DOCUMENT RESUME

ED 293 693 SE 049 028

AUTHOR Johnson, Elmima C.; And Others
TITLE Cooperative Science: A National Study of University and Industry Researchers. Case Studies. Volume II.
INSTITUTION National Science Foundation, Washington, DC. Div. of Industrial Science & Technological Innovation.
REPORT NO NSF-84-39A
PUB DATE Nov 84
NOTE 48p.; For volume 1 of this study, see SE 049 027.
AVAILABLE FROM National Science Foundation, Forms & Publications Unit, 1800 G Street NW, Room 232, Washington, DC 20550 (free while supply lasts).
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Biology; *Case Studies; Chemical Engineering; Chemistry; *College Science; Computer Science; *Cooperative Programs; Federal Aid; Fisheries; Higher Education; Programing Languages; *Research Projects; *Research Universities; *School Business Relationship; Science Education

ABSTRACT

This report presents nine case studies of Industry/University Cooperative Research (IUCR) projects supported during 1978-1980 by the National Science Foundation. The intent of this document is to provide readers with a qualitative picture of cooperative science as practiced under the IUCR program. The information presented in this report is designed to be illustrative and hypothesis-generating rather than definitive and hypothesis-testing. The case studies presented include projects that deal with: (1) computer language systems; (2) fluid dynamics; (3) filtration processes; (4) electrochemistry; (5) nuclear science; (6) polymer chemistry; (7) limnology and fisheries biology; (8) non-destructive testing; and (9) chemical engineering. (TW)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED293693

COOPERATIVE SCIENCE: A NATIONAL STUDY OF UNIVERSITY AND INDUSTRY RESEARCHERS

CASE STUDIES

PRODUCTIVITY IMPROVEMENT RESEARCH SECTION

DIVISION OF INDUSTRIAL SCIENCE & TECHNOLOGICAL INNOVATION

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

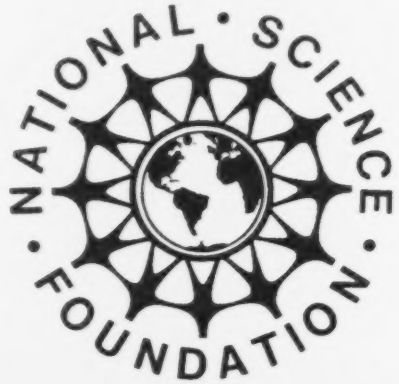
☐ Minor changes have been made to improve reproduction quality

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

NSF

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."



NATIONAL SCIENCE FOUNDATION

VOLUME II

NOVEMBER 1984

BEST COPY AVAILABLE

SE 049 038

The Foundation provides awards for research in the sciences and engineering. The awardee is wholly responsible for the conduct of such research and preparation of the results for publication. The Foundation, therefore, does not assume responsibility for such findings or their interpretation.

The Foundation welcomes proposals on behalf of all qualified scientists and engineers, and strongly encourages women and minorities to compete fully in any of the research and research-related Programs described in this document.

In accordance with Federal statutes and regulations and NSF policies, no person on grounds of race, color, age, sex, national origin, or physical handicap shall be excluded from participation in, denied the benefits of, or be subject to discrimination under any program or activity receiving financial assistance from the National Science Foundation.

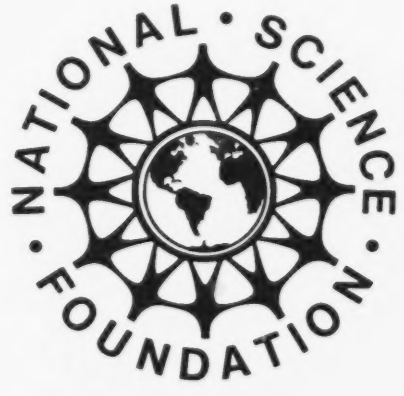
NSF has TDD (Telephonic Device for the Deaf) capability which enables individuals with hearing impairments to communicate with the Division of Personnel Management for information relating to NSF programs, employment, or general information. This number is (202) 357-7492.

COOPERATIVE SCIENCE: A NATIONAL STUDY OF UNIVERSITY AND INDUSTRY RESEARCHERS

CASE STUDIES

PRODUCTIVITY IMPROVEMENT RESEARCH SECTION

DIVISION OF INDUSTRIAL SCIENCE & TECHNOLOGICAL INNOVATION



NATIONAL SCIENCE FOUNDATION

VOLUME II

NOVEMBER 1984

by

Elmima C. Johnson
Louis G. Tornatzky
Lynne R. Schlaaff

Productivity Improvement Research Section

Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily represent the views of the National Science Foundation.

CONTENTS

EXECUTIVE SUMMARY v

CHAPTER 1: OVERVIEW OF THE STUDY 1
CHAPTER 2: A PROJECT ON COMPUTER LANGUAGE SYSTEMS 4
CHAPTER 3: A PROJECT ON FLUID DYNAMICS 9
CHAPTER 4: A PROJECT ON FILTRATION PROCESSES 13
CHAPTER 5: A PROJECT ON ELECTRO CHEMISTRY 17
CHAPTER 6: A PROJECT ON NUCLEAR SCIENCE 21
CHAPTER 7: A PROJECT ON POLYMER CHEMISTRY 24
CHAPTER 8: A PROJECT ON LIMNOLOGY & FISHERIES BIOLOGY .. 28
CHAPTER 9: A PROJECT ON NON-DESTRUCTIVE TESTING 32
CHAPTER 10: A PROJECT ON CHEMICAL ENGINEERING 37

EXECUTIVE SUMMARY

It is difficult to capture the essence of the descriptive case material with a few well-chosen generalizations or "nuggets." These IUCR projects were complicated undertakings, and for many of the participants they represented significant milestones in their professional lives. Nonetheless, there appears to be at least one integrating concept to apply to the results.

The concept that might be employed is the *social network*. A social network is an organizational and sociological concept that has been used to describe the complex web of communication and interaction that characterizes most human groups. It has been used as an analytical tool to understand phenomena such as friendship cliques, bureaucratic organizations, and scientific specialities. The nine cases presented here confirm the importance of social networks in the prior relationships between the participants, the management of the projects, and the results achieved.

Prior Relations and Project Initiation

The development of these cooperative relationships was a slow and cumulative process. Research collaboration did not result from a single chance encounter, nor was it a product of an organized search for compatible technical expertise. Most if not all of these projects were preceded by extensive interpersonal contact, collaboration, mentorship, and, in some cases, friendship. There were several prior student-faculty relationships in these IUCR projects, as well as consulting relationships, sharing of papers, and the like.

For example, six of the nine projects involved prior consulting relationships between the university researcher and the collaborating firm. In another project, while there was no prior consulting relationship, this was simply because the firm did not even exist until it was created by a former university professor. In only one project was there no concrete prior relationship between the principals, although in that case they were aware of each other's work. There were other connecting links. Four of the projects involved industry researchers who were current or former students at the collaborating university. In one case a mentor/student relationship had extended from undergraduate days through the Ph.D. In two additional projects the industry investigators were former or current faculty at the university. Five projects involved co-investigators who had performed research and/or published together. One project had neighbors as collaborators.

For the most part, these were relationships between peers. Eight of the nine academic researchers were full professors and the industry investigators were primarily senior scientists in their organizations. Full-time cross-sector work experience (academics in industry and vice versa) was also comparable in seven of the projects, although this experience was generally negligible for both sets of participants. The organizations involved in these projects were also comparable in scope/size. Seven of the nine firms were Fortune 500 companies; and seven of the universities involved ranked in the top 100 in total R&D expenditures. These observations were generally consistent with the findings in the quantitative analysis of the 118 projects.[1]

Project Management/Coordination

Interaction during the course of the projects reflected the pattern that had developed prior to their initiation. In the terminology of interorganizational sociology, the industry and university scientists seemed to be quite adept at "boundary spanning" or reaching beyond their nominal institutional constraints. The course of each project depended heavily on ongoing intra-project communication. One comes away from reading these cases with a vision of exciting intellectual interchange that persisted over the course of many months. Frequent phone calls, meetings, and late night "bull sessions" all seemed to be important parts of these projects. While such communication patterns are probably characteristic of any successful research team, they were particularly crucial for these cooperative projects.

For the most part the university and industry co-investigators each managed autonomous sub-projects, which complemented the work being conducted by their collaborators. This relative independence exacerbated the need for coordination between the two efforts, and the richness of these communication linkages was considerable. In all of the projects save one, there was phone or face-to-face communication that was regular and informal. Despite the fact that physical distance was often considerable (ranging up to 3,000 miles apart) the ease with which the research communicated yielded an enhanced collaborative effort. These media linkages were extended by "embodied" knowledge transfer; in four of the projects there was personnel exchange between the university and industry sub-projects.

[1] Elmima C. Johnson and Louis G. Tornatzky, *Cooperative Science: A National Study of University and Industry Researchers* (Washington, D. C.: National Science Foundation, 1984).

Results of Cooperation

There were several tangible results from the cooperation. The nine cases produced at least three books, numerous articles, and a minimum of five MA/PhD theses. One PhD thesis was published as a book (the first time in the history of that department) which was enthusiastically received. One post-doctoral researcher developed an important experimental procedure, and credited the opportunity to work with an industry scientist and use sophisticated industry equipment as crucial elements in his success.

The nature of the science itself also seemed to change as a result of the IUCR experience. In two-thirds of the cases methodology and research foci were seen as changed as a function of the cooperative interaction. Participants seemed to have altered their epistemologies positively and significantly. The cases are replete with admissions by mature scientists of how their perspectives on their science had changed. In some sense the cooperative science practiced in IUCR may be a way of pressing the boundaries of what Kuhn called "normal science."[2] Indeed, one of the issues that might be addressed in subsequent work is the extent to which cooperative science alters the paradigm of the inquiry.

Personal outcomes varied. Overall the researchers saw increased prestige among colleagues and in the larger scientific community as the primary benefit. More tangible rewards, such as salary increases or promotions, were mentioned most frequently by industry scientists.

Two industry investigators were able to leverage knowledge gained through the project to secure better positions in other companies. Another researcher obtained a permanent position within his firm based on the IUCR project. One university researcher received an award based on his work.

Finally, it is worth commenting on the generally positive nature of the experience observed among IUCR investigators. While many participating scientists approached the cooperative venture with some misgiving, virtually all of them came away as enthusiastic advocates. While these kinds of outcomes are probably unrelated to more specific economic and technological outcomes, at least it appears that cooperative science will be a growing force in the American intellectual community.

There were minor criticisms about program management and a few related suggestions. Criticisms included the length of the review process, uncertain funding, and the limited range of fundable topics. (Most of these have been resolved by subsequent changes in IUCR program policy.) The most significant suggestion for program expansion was to match university and industry scientists with similar research interests using vehicles such as workshops, industry sabbaticals, etc.

[2] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, International Encyclopedia of Unified Science (2nd ed.; Chicago: University of Chicago Press, 1970), pp. 10-22.

Highlights

Cooperative science between university and industry researchers is an incredibly complex logistical, interpersonal, and organizational undertaking and a comprehensive summary of these projects is difficult. However, the following statements highlight major trends in the case analysis:

- There had been extensive interpersonal contact between university and industry scientists prior to the IUCR projects including collaboration, student/faculty relationships and in some cases friendships.
- The co-investigators were, for the most part, academic and experiential peers in their respective fields. Their organizations were also comparable in scope/size.
- Full-time cross-sector work experience was comparable, though negligible for both sets of researchers.
- Intra-project communication and coordination was frequent and generally informal. It transcended organizational boundaries and distance.
- Although approximately one-half of the projects were still in progress, the researchers anticipated a variety of intellectual products including books, articles, etc.
- Changes in the nature of the science (i.e., in research methods and topics), were reported in two-thirds of the projects.
- Increased prestige was the primary personal benefit emphasized by both sets of researchers. More tangible benefits (salary, promotion) were anticipated primarily by the industry researchers.
- Both university and industrial participants expressed a high degree of general satisfaction with the IUCR project, including technical quality of the research, communication patterns, and project administration.
- Participants suggested that NSF play a more active role in matching university and industry scientists with similar research interests.

Chapter 1

OVERVIEW OF THE STUDY

Introduction

This report presents nine case studies of Industry/University Cooperative Research (IUCR) projects supported during 1978-1980 by the National Science Foundation's Division of Industrial Science & Technological Innovation. The intent is to provide readers with a qualitative picture of cooperative science as practiced under the IUCR program. The information presented here is illustrative and hypothesis-generating rather than definitive or hypothesis-testing. We describe ongoing processes, rather than make causal inferences or quantitatively-based generalizations.

Cooperative research in the IUCR model is probably not the norm in American science. To have two or more investigators, separated by distance and institutional affiliation, combine their efforts into a common intellectual product is a difficult undertaking indeed. Moreover, the separation between university and industry scientists in this country has historically been epistemological as well as geographic. Universities in the U.S. have been the home of basic research; American industry has been primarily concerned with applied research and development.

The IUCR program represents one attempt to bridge these gaps. The program sponsors research projects in the physical and biological sciences and in engineering performed *jointly* by university and industrial scientists. Projects focus on fundamental science, but are also expected to be relevant to industrial operations and technology development. Since the inception of the program in 1977 over 250 projects have been funded. Each of these projects represents an interesting story in both the advance of science, and in the organization and management of a logistically complex intellectual task. The case studies presented here are a small sample of those experiences.

This report will present data which hopefully can enhance our practical understanding of industry-university collaboration, and also add to the scholarly literature on innovation processes and organizational behavior.

Relation to Other Assessment Activities

This study is one component of a three-part assessment of the IUCR Projects Program undertaken by the Productivity Improvement Research Section at NSF. The first phase of that assessment began in 1981 and consisted of a descriptive analysis of 118 grants awarded in FY 78-80, the first three years of program operations. Information on grants, participants and their organizations was obtained from archival sources, primarily grant files. The study was completed in April, 1982.[3] The second part of the assessment was a mail survey of the 236 university and industry researchers involved in the 118 projects identified in the first phase. The purpose was to determine the nature of the role relations and transactions involved in the typical IUCR project, and results and benefits achieved by both industry and university participants. The results of this survey are summarized in a companion volume.[4] As the third phase of the assessment effort, nine of the 118 projects were selected for case study analysis. The purpose was to chronicle the implementation of the projects, highlighting participant views of this collaborative research venture, and its impact on them and their institutions. That effort is described in this volume.

Issues and Questions

While much has been made of the importance of knowledge transfer and dissemination in the innovation process,[5] there have been few organized attempts to influence that process on a large scale. The IUCR program is one of a very few Federal efforts to develop explicit bridges between the world of academia and the world of commerce. A major premise of the program is that university basic science can be more attuned to industrial interests without sacrificing its essential character, and correspondingly that industrial science can be enriched by linkage to theoretically-driven research. The issue, of course, is how to facilitate this reciprocal knowledge transfer between university and industry organizations.

The IUCR program attempts to institutionalize such interorganizational interaction through the funding mechanism itself. Within the short history of the program there have been both recurrent themes and con-

[3] Elmima C. Johnson, Louis G. Tornatzky, Patti Witte, and Claire Felbinger, *Assessment of the Industry/University Cooperative Research Program (IUCR): Interim Report 1. Descriptive Analysis of Projects FY 1978-1980* (Washington, D. C.: National Science Foundation, 1982).

[4] Elmima C. Johnson and Louis G. Tornatzky, *Cooperative Science: A National Study of Industry and University Researchers.* Assessment of the Industry/University Cooperative Research Projects Program (IUCR). (Washington, D. C.: National Science Foundation, 1984).

[5] Louis G. Tornatzky, J. D. Eveland, Myles G. Boylan, William A. Hetzner, Elmima C. Johnson, David Roitman, and Janet Schneider, *The Process of Technological Innovation: Reviewing the Literature* (Washington, D. C.: National Science Foundation, 1983), pp. 155-175.

siderable variability in how IUCR projects evolve, and in the nature of outcomes achieved. The purpose of this study, and of the entire three-part assessment effort, has been to describe how IUCR projects usually developed, and, if possible, to discover what project features contributed to successful technical and organizational outcomes.

In designing the assessment studies, it became abundantly clear that university/industry research interaction is not an area that has received much empirical attention. A review of the literature indicated that there were some useful concepts that could be borrowed from organizational sociology, but few firm findings.[6] As a result, the selection of variables and variable domains for the studies was less focused than it might have been in a more mature area of inquiry. Nonetheless, there were several sets of factors which seemed useful to examine.

For one, we were interested in the *demographics* of participants. What kind of scientists, from what kind of institutions, become involved in cooperative projects? Were they "outliers" or well-known investigators? Were the companies small entrepreneurial enterprises or large companies?

A related issue concerned the *prior history* of interaction between participants. Could it be assumed that the IUCR program itself fostered research interaction between former strangers, or rather that it served as a catalyst after a long prior history of other kinds of exchange? To what extent were IUCR collaborating scientists involved in friendship or collegial networks with each other prior to a project? Similarly, what was the "track record" of cross-sector interactions between the participating institutions?

We were concerned not only about the general history of prior interactions, but also about the specific events that led to the *initiation* of an IUCR project. How did the principals hear about the program? What role did NSF staff play? Would the project have been implemented or even considered in the absence of an IUCR program? Who took the initiative in constructing the research project and proposal?

We were also interested in the *management* of these projects. How did separation in affiliation and geography affect project management, group dynamics, communication patterns, and the like? A particularly important aspect of this line of inquiry was how the two sets of investigators—university and industry—coordinated their activities and divided their responsibilities. How does a geographically and organizationally decentralized project work?

Finally, we were interested in the *outcomes* of IUCR projects—not only intellectual and technical outcomes, but possible commercial results. To what extent could we expect new products or processes to be generated by the cooperating company? What contributions to general science might result? Within the general category of effects was the question of how participation changed the participants themselves. Did university scientists become more aware of industrial needs and operations, and vice versa? Did scientists and students alter their career directions?

These and other questions have guided the data collection in this study, and in the accompanying national survey. Again, our intent in presenting these cases is to capture in a descriptive fashion the nature of cooperative science practiced in the IUCR program.

Methods and Procedures

Selection of Projects

There was no attempt at random selection of projects representative of the entire population; projects were selected in order to maximize variability along certain dimensions including firm size, public versus private universities, and distance between the cooperating investigators. Also included was one project which was selected by the IUCR Program Manager as exemplary in terms of quality of the research, results, and the level of industry participation. In all, nine projects were selected.

Data Collection

The two interviewers, members of the PIR staff, were briefed by the program managers on the technical aspects of each project prior to the site visits. In addition, each program manager contacted his grantees to alert them to the purpose of the visit and to elicit their cooperation. Researchers were informed that their participation was voluntary, that this visit was not a program review and would not influence future funding decisions. The projects were in various stages of operation at the time of the site visits and several were in the process of applying for renewals. All had been in operation at least one year. The site visits occurred in August-September 1982, and included a review of responses to the questionnaire that was used in the national survey, as well as an indepth discussion of research relationships and the impact of the project on the collaborating organizations. Other project team members and organization officials were interviewed when available. All interviews were tape recorded and transcribed.

The strategy of the case study data collection was straightforward: encourage our respondents to elaborate in a more open-ended context the answers given

[6] Elmima C. Johnson and Louis G. Tornatzky, "Academia and Industrial Innovation," in *New Directions for Experiential Learning: Business and Higher Education—Toward New Alliances*, ed. by G. Gold (San Francisco, California: Jossey-Bass, 1981), pp. 50-53.

to the structured instrument used in the companion survey. In addition, an attempt was made to obtain convergent data by talking to other personnel at the sites, to observe interaction, to review documents, and to get an experiential "feel" for each project.

Analysis and Case Format

The cases presented here have been distilled from over 1,000 pages of transcripts and written responses to a lengthy questionnaire. Each transcript and set of questionnaire responses was organized into the following categories: 1) project and participants; 2) prior cross-sector collaboration; 3) initiation of the collaborative project; 4) project management and decision making; 5) coordination; and 6) benefits and outcomes. This format was used in each case report and was developed to highlight similarities as well as differences in project activities.

We have attempted to capture the flavor of the interactions as well as to present factual information concerning project logistics. Extensive use of direct quotation has been made. Since some of the researchers requested anonymity, we have disguised the identity of all of the projects. Obviously this was difficult to accomplish in some cases and required that we limit our discussion of the technical nature of the research. Each case study was reviewed by the respondents for accuracy and propriety, and was approved for publication. However, primary authorship of these cases rests with PIR staff.

The cases are presented as nine separate chapters. No particular ordering of the cases is intended. Each of the case chapters should be considered as both a unique combination of researchers and areas of science, and also one of a set of stories with general and recurring themes.

Chapter 2

A PROJECT ON COMPUTER LANGUAGE SYSTEMS

Overview of Project and Participants

The focus of this project was computer language systems, in particular the conversion of language systems used by programmers into machine languages used by the computers themselves. The participating firm was a Fortune 500 electronics company; the participating university was a major land grant university in the midwest. The university principal investigator was an electrical engineer; the industry principal investigator was a computer scientist. The university researcher was in his mid-40's, and had spent his entire academic career at this university, with a brief tour of one year in industry. His department was not at the time among the top ten in the field, although this particular researcher had been quite professionally active, received several grants, and had published extensively.

The industry researcher, in contrast, had spent nearly a decade in the electronics industry. Virtually all of his time had been in a research and development capacity. During the period of the IUCR grant, the industry researcher was working towards his Ph.D. degree, and in fact the IUCR project was a major portion of his dissertation. Despite his student status, the industry researcher remained a part-time employee of his firm, and worked full-time there during the summer months. After the termination of the IUCR grant, the industry participant changed companies, leveraging research skills and knowledge acquired during the project into a more responsible position.

The project itself was supported by 2 two-year grants from the NSF funded consecutively. No funds were given to the industry participant.

Prior Cross-Sector Collaboration

Prior University Activities. The faculty member involved in this project had extensive ongoing relationships with industry, and with the participating company in particular. He had contract research projects with industry for 10 to 12 years, as well as individual consulting relationships with several firms, including two in western Europe. The faculty member had also successfully placed students in industrial settings as part of their training.

The professor had a lengthy consulting arrangement with the company involved in the IUCR project. In the context of this consulting relationship, his work became known to a mid-level scientist in the firm, who eventually became the industry co-investigator on the project.

Prior Firm Activities. Prior to the initiation of this IUCR project, the participating firm had collaborative research and consulting relationships with university faculty from a variety of institutions. The industry scientist's situation was somewhat unusual in that he was part of both the university and the firm. He had left his company to pursue a Ph.D. program which was intimately tied to the IUCR project that evolved, and during the four calendar years that he spent at the university he was still on his company's payroll as a part-time employee, and had continued access to lab and computer facilities. The two investigators had never actually met prior to the industry scientist's returning to the university.

Initiation of the Collaborative Project

Preliminary Discussions/Work. Prior to the awarding of the NSF grant the university professor and the industry scientist had already made tentative plans to implement a project in the research area. The firm researcher had initially discussed a prospective project with the R&D managers at his firm, and had received essentially a negative response. A subsequent query to a product group within the company received a more sympathetic response, to the extent that the possibility of an in-kind contribution of personnel and computer time became a possibility. To a significant degree the conceptualization of the research project was underway before both the university and industry scientists became aware of the NSF program. The NSF program became the catalyst to successfully implement their plans.

Role of NSF IUCR Program. During these preliminary discussions the university researcher became aware of NSF's IUCR program. The university office of extramural research periodically circulated a flyer on new funding sources and programs, and the university professor read an issue in which the IUCR program was spotlighted. He contacted the industry researcher/graduate student, and the two of them decided that it would be worthwhile to write a proposal.

Both the university and the industry researchers felt that a project would not have been implemented, at least of the same scope, without the IUCR program. The industry researcher felt that some project might have been undertaken, but it would have been much more narrowly focused, and probably would not have contributed to the larger scientific literature. More emphatically, the university professor felt that the proj-

ect would not have been undertaken at all in the absence of the NSF grant. The academic norms at the time would not have been supportive, and he might never have thought of approaching industry with this type of research project. In addition, the nature of the work done could not have been accomplished without access to some of the sophisticated research equipment available in the industrial firm. The IUCR program enabled the researchers to move beyond mere short-term development issues, into more theoretically-driven issues of relevance to the larger scientific community.

Application Process and Internal Negotiations. Once the project proposal had been written, it was treated in a fairly straightforward manner in both the university and industry setting. An understanding was reached regarding use of underutilized computer facilities, in-kind contributions had been agreed upon, and the actual processing of the grant proposal was routine.

Project Management and Decision-Making

Project Structure. As were some of the other projects described in this volume, this project was an organizationally and logistically complex effort. There were three active research teams operating concurrently, at two geographically separated sites, working under the supervision of two different research supervisors. Complicating the management issues was the fact that one of the researchers was a graduate student and the other was a tenured professor. Personnel involved in the various sub-projects included undergraduate students, graduate students, and full-time professional engineers.

Specifically, the university professor supervised two masters level students on one sub-project, whose work comprised their master's theses. A second sub-project conducted at the university was supervised by the firm principal investigator/graduate student, and was staffed by five undergraduate students working part-time. The third sub-project was conducted at the firm itself, was supervised by the firm principal investigator from the university, and was staffed by two master's level engineers who were permanent employees of the firm. This team was supervised largely by "remote control" via letter and telephone. To a significant degree the three sub-projects operated autonomously. The university professor had very little to do with the supervision of the firm-based team or of the undergraduate team, and vice versa.

Management Style. The managerial style adopted by the university and firm researchers in their areas of project responsibilities differed considerably. For example, the university professor was heavily involved in problem definition and identification of research issues, establishment of the administrative structure of the project, personnel and selection of equipment. However, he was not extensively involved in bench level science, and the actual collection and analysis of data. This approach was partly a function of the professor's personal style, and more directly influenced by the fact that the sub-project under his direction was staffed by students doing their master's thesis. The thesis experience demanded a certain amount of self-direction for the involved students.

Management of the five undergradudate students by the industry researcher took quite a different approach. The industry co-investigator adopted a very directive and structured approach with the undergraduate employees. His view was that these individuals were relatively unsophisticated in terms of the science involved, and needed explicit direction and close supervision. One vignette is worth noting. Since the work conducted by these undergraduates was part of the firm researcher's dissertation project he needed to defend the scope and management of the work to his dissertation committee. There was considerable skepticism expressed by a professor on the committee about whether the work could be done in the nine months that the firm co-investigator had allocated for these activities. This committee member estimated that the work would take upwards of two and a half years to accomplish. There was some sheepishness and surprise on the part of faculty when in fact the firm researcher was able to motivate his team of undergraduate workers and make the deadline.

Interestingly, the management style adopted by the industry researcher with his team at the home firm was considerably different, and indicated a high degree of flexibility on his part. The personnel there were his educational and professional peers. In addition, the unit in which these two engineers worked tended to be operated in a collegial manner, and the supervisor relationship between the firm co-investigator and these two staff was of that nature. There was no perceived need to spell out in explicit detail the research tasks to be performed, or to provide close supervision of activity. As a result, a "hands-off" supervisory style was successful despite the fact that the work was done several hundred miles away from the university.

Coordination

Coordination Within the Project. Given the existence of three sub-projects, plus the geographic dispersion of the overall project, there was an obvious need for close coordination and communication between the two principal investigators. There were several factors that facilitated this necessary interaction. For one, the two co-investigators had offices on adjacent floors at the university. Several times a week they would meet face-to-face, and talk about activities of their respective teams. The student-professor relationship

also contributed to coordination. The university professor was the firm scientist's dissertation advisor, and the performance of the advisory function provided many settings in which coordination and communication could take place. Although the university and industry researchers were co-investigators on the grant proposal, and were thus presumably equals, one was clearerly more equal than the other. As the firm researcher pointed out, "as a thesis student . . . one is very careful." This is not to discount the fact that the faculty-student relationship was not a traditional one, and over the course of the project a great deal of mutual respect developed between the two researchers.

The firm researcher took upon himself much of the coordination between the various sub-projects. For example, most of the contacts with the researchers at the firm site were made by him, although the university researcher did make one or two site visits to the firm. After the industry scientist returned to the firm, during a latter period in the project, he continued his coordination efforts. Over a two-year period he made several return visits to the university, about once every two or three months. Some of these visits were not paid for by grant funds, but were made in the context of personal or other business trips to the metropolitan area in which the university was located. These coordination meetings were of course supplemented by frequent telephone contact, exchange of written documents, and some use of electronic mail.

There was also some intraproject communication that was facilitated by exchange and placement of students. During an early part of the project an undergraduate student spent a summer internship at the participating firm; during a latter part of the project a masters level student worked at the firm for a summer in the research lab. Another type of educational knowledge exchange occurred when one of the engineers at the firm spent two weeks studying under the university researcher, to better understand some of the more theoretical aspects of the work. This was in effect on-the-job training for the engineer, to enable him to better perform his functions on the ongoing project. This exchange was undertaken after the industry researcher had returned to his home firm, and decided it would be useful to send his colleague directly to the university professor or, in his words, to "the horse's mouth." It should be noted that not only did this engineer receive information from the university professor, but during his brief stay he was able to provide valuable feedback to the graduate students at the university who also were working on the project.

Coordination and Reporting External to the Project. In addition to communication among members of the project team, there was also some limited degree of communication with other individuals in the firm and university. For the university principal investigator there were no formal requirements for ongoing briefings or reporting of project activities. However, the university researcher did have his expected obligations to publish and contribute to the scientific literature. In addition, the university researcher kept one of the associate deans in his college well apprised of the project, and there was some ongoing interest from researchers in another academic department who were pursuing similar research interests.

As far as the firm researcher was concerned, he periodically informed the staff in the central R&D and production units about the project's progress. In particular, there was one individual in central R&D who was working on a similar project, and who was involved in a fairly constant dialogue with the firm co-investigator.

Benefits and Outcomes

Technical Outcomes. This research project generated various intellectual products. These included one book, two articles, and various internal reports and technical documents. Important to the university participants were the two masters theses, and the one Ph.D. dissertation that resulted directly from the project.

It should be noted that the book that resulted from this project was written by the industry participant, and constituted his doctoral dissertation. This was the only dissertation in the history of the department that had ever been published as a book, and moreover it achieved significant sales.

From the perspective of both university and industry researchers these tangible products were merely the visible evidence of a much more intangible increment in scientific knowledge. Both researchers felt that the work contributed significantly to basic understanding of the processes being investigated. The industry participant felt that the project expanded knowledge of the technical area and enhanced the quality of industrial and university research.

Knowledge Utilization. One manifestation of technology transfer is the exchange and dissemination of knowledge emanating from the project. The university investigator received some requests for information from within the university, but there were more frequent requests from external users. Within the university a group of researchers in the computer sciences department were investigating similar issues and were interested in the results of the project as they came out. Similarly, the university and firm researchers received requests for reprints and results, primarily from researchers in other universities. In contrast, the industry researcher received few requests from within his company, primarily from two sources. As in the case of the university, these internal users were pursuing lines of work compatible with that pursued in the IUCR project.

Aside from these more tangible instances of knowledge utilization, there is also the issue of the extent to which the project influenced the research agenda of the participant organizations. One possible type of influence would be a greater legitimation and higher priority given to this type of work in both the industry and university setting. Another type of outcome would be a more specific utilization of the findings as a lead in subsequent research.

There were changes in research priorities and follow-on work resulting from the project; however, the extent to which this occurred was probably less than optimal. On the university side, the project seemed to yield some grudging acknowledgement by the professor's colleagues that this type of industry-relevant work might be worth doing. This conclusion was abundantly clear for the university participant himself, who came to realize that working with industrial people brought problems to his notice that might have been ignored. In commenting on the limitations of traditional academic work, the university researcher pointed out the following:

> You tend to get the idea that once some solution has been shown to exist, the problem is finished, whereas it is a long hard road between the solution as perceived to exist and the technology in place to serve humanity in some sense.

The problems of applying the results of the research in industry were quite complex. It should be recalled that the industry researcher did not come from the R&D group within the company, but rather was affiliated with a product group. As a result, the regular research group within the firm was relatively uninterested in the work and had only "signed-off" on the project because it did not affect their own funding.

The NSF project did stimulate follow-on work in the firm but not with active support of the main line R&D unit. One project was taken in another non-R&D division, and a second project was only undertaken with further NSF money. The industry researcher felt that the project had caused some changes in research methods and procedures used in the participating company, and would almost certainly improve future projects, plus ultimately yielding commercial products.

However, more of these benefits will likely be realized in another firm. Although the industry researcher was eventually given a position in the R&D group, he was never given sufficient resources or a clear mandate to pursue the line of work undertaken under the NSF grant. As a result, he felt personally and professionally frustrated and moved to a larger electronics company. In this new setting he is extending the research conducted in the IUCR project. It is noteworthy that in his new company the industry researcher is again talking to his university-based collaborator about possible joint work, with or without NSF funding. In a sense, the research priorities of an industrial company have been significantly altered, but not the company that originally participated in the work.

The university researcher echoed this disappointment regarding technology transfer and implementation in the original participating company. In his view, the issue of technology transfer was the biggest negative aspect of the project, and he noted that the shortsighted posture of the company seemed to be the major problem. In his view, the industrial participants tend to get "jerked about" by a company's short term priorities. In his words:

> It's hard to keep an industrial person on a project like this for a long time because the company doesn't see it as something that is primary to their business of making money. If there is a fire some place they grab the guys that you've got working in the project and say "sorry, forget that."

It should be noted that the university researcher is still working with the orignal host company, and has some hope that the knowledge use situation may improve.

Personal Outcomes. Both university and industry researchers viewed their participation in the project as a professional growth experience. The university researcher felt that the industrial participation provided a strong reality check for his academic research. In his words:

> What makes me continue to do this university-industry business is that if you do something in the university you tend to get a kind of an academic flavor to it, which causes you to overlook problems that will exist in industry. The ability to have a check—to have somebody out there saying this is a bunch of bologna—I find that useful.

For the industry researcher, the NSF grant "opened doors" and enabled him to secure company resources which would have been difficult to obtain otherwise. He received much more in the way of tangible rewards for participation in the project than did the university professor. For the industry researcher, participation in the project positively affected promotion, salary, and visibility among his professional peers in industry.

A more indirect personal outcome was the job placement experience of one of the undergraduate students on the project. Apparently this individual was quite talented, had performed well on the project, and the participating company made a fairly generous offer (which the student rejected). The student was subsequently hired by another major company in the electronics industry.

Policy Issues

A major theme expressed by both university and industry researchers was the catalytic function of the

IUCR grant. The NSF program was seen as providing a rather unique incentive and structure for encouraging university/industry research relationships. Correspondingly, many of their suggestions for program changes or experimentation emphasized this catalytic and incentive function.

For example, one suggestion was that cost-sharing by industry ought to be a cash contribution rather than an in-kind contribution of staff or resources. The industry researcher felt this would enhance the likelihood of the research being used in his own company.

The university researcher also emphasized the catalytic function of the NSF in promoting university/industry cooperative research. In fact, he recommended that the NSF decrease its role as a granting agency and increase its role as a broker of cooperative research. For example, he suggested that the Federal government try to match university and industry performers who have similar research interests.

Neither the university nor industry investigator felt that a program such as IUCR would result in research being excessively applied in nature. They felt that the internal incentives structure of the university would preclude this, and that university researchers would only become involved in projects which allowed them to publish in the open scientific literature.

One common theme was the perceived importance of the government in providing a general milieu for this type of collaborative work. Although the specific mechanisms involved were unclear to the respondents, they felt that various policy levers (e.g., tax policy) might provide a viable device. Although neither the university nor industry researcher felt that the grant application procedure was particular onorous, they both felt that cooperative research could also be performed in the absence of grants. Whether they would have felt this way if they had not participated in an NSF supported cooperative project is unclear.

Both the university and industry researchers felt that the IUCR project was a way of "leveraging" scarce resources. For the university researcher it was a way of receiving industrial feedback to sharpen the academic research agenda. For the industry participants IUCR served as a vehicle to support basic research that might have long range industrial implications, without necessarily gearing up an entire laboratory effort to perform this task. As the firm researcher put it:

> Even though our two goals were different, . . . they meshed so perfectly that you couldn't have planned it any better. And I think there are many of these sorts of situations out there where two different goals, two different groups of people, can be brought together and realize that they complement one another.

Chapter 3

A PROJECT ON FLUID DYNAMICS

Overview of Project and Participants

This project was in the general area of fluid dynamics, with a particular emphasis on drag theory and the design of aerospace vehicles. The participating firm was a large aerospace company; the participating university was a major technological university in the south. The university principal investigator was in his late 40's, and had been trained as a mechanical engineer, receiving both bachelor's and Ph.D. degrees in that field. His current academic appointment was in a department of aerospace engineering. He had spent six years working in the aerospace industry following his Ph.D., advancing to the position of research manager, but had been in the university for over seventeen years. The university professor had published widely, was well-known in his field, and had received several awards. His department was considered among the highest rated in the field.

The industry scientist was also in his late 40's, and had a Ph.D. in aerodynamics. He had spent over a decade working with his present company, although prior to that he had spent a few years in a government research laboratory. The man was a staff scientist in his company, and supervised a small group of researchers. The industry scientist had very little direct experience working in a university context, though he had worked for brief periods with universities on a number of occasions.

The project was supported by a two-year IUCR grant. The work was to include theoretical development at the university site, and experimental work in the company research facilities. Both the university and the participating firm were located in the same state, and there was very little geographic hindrance to maintaining contact between the two parties.

Prior Cross-Sector Collaboration

Prior University Activities. The university researcher had some consulting relationships with large companies in the aerospace industry, including the firm involved in this IUCR project. In addition, the university had placed students in the aerospace industry, and participated in contract research projects with companies in the field.

Prior Firm Activities. The participating firm had a long history of working with universities. These included consulting relationships, contract research projects, and the placement of students. Pertaining to the latter, the industry researcher had participated as a member of a Ph.D. dissertation committee with another university. The participating firm also had some prior contact with another university in the particular research area that was studied in this IUCR project. Apparently the industry researcher had a friend who was a professor at a Canadian university, who had brought to his attention new results in this research area in the 1970's. The already-existing consulting relationship with the university professor proved to be quite compatible with the proposed research.

Initiation of the Collaborative Project

Preliminary Discussions/Work. As noted above, there was some prior discussion about this research area with both the Canadian professor and the professor who actually became involved in the IUCR project. The university and industry scientists worked together in the development of a paper on the research area, the content of which overlapped with their proposal to the NSF. This research area was not the primary activity being pursued by the university scientist at the time, but the existence of a prior consulting relationship enabled the firm and university researchers to rapidly focus their work on this promising new line of research. Much of the initial impetus for the project came from the industry scientist. He asked for some theoretical help from the university professor, which eventually evolved into the working relationship of the IUCR project.

Role of NSF IUCR Program. Both the university and the firm became aware of the IUCR program at about the same time. The university's office of research and development had circulated the IUCR brochure among various departments; the industry scientist learned about the program from one of his associates in the company.

Both the university and industry scientist felt it unlikely that the project would have been initiated in the absence of NSF support. Ironically, the industry scientist felt that internal support would have been difficult, not because of the inapplicability of the project, but because it was so broadly applicable across a number of areas that it would be difficult to get specific justification. In his view, the value of the NSF award was that it enabled "an injection of money at a point where the program was becoming difficult to sustain within the company."

The nature of the NSF IUCR grant also enabled the two researchers to perform compatible research func-

tions. Much of the theoretical/conceptual work was handled by the university scientist on the campus; most of the empirical and experimental work was conducted at the industry setting, using the extensive wind-tunnel facilities of the company.

Application Process and Internal Negotiations. Once the university and industry scientist had agreed to pursue this line of work, the actual writing of the proposal was fairly straightforward. On the university side the processing and sign off procedures for the proposal were also routine. The university had a fairly lengthy history of involvement with both the NSF and this particular company.

There were some logistical difficulties in processing the grant application as far as the firm was concerned. These difficulties centered around the IUCR program requirements regarding cost-sharing and in-kind contribution of resources. Since such arrangements were not commonplace at this particular company, the industry scientist had to engage in internal politicking to secure the necessary approvals.

Project Management and Decision-Making

Project Structure. The university scientist described the project as "two separate teams joined at the head." This tongue-in-cheek description is particularly apt. Virtually all of the empirical/experimental work was done at the firm wind tunnel; virtually all the conceptual/theoretical work was done at the university site. Thus, two quite different but clearly compatible subprojects proceeded in parallel in two different settings.

Staffing at the industry site included no more than four individuals in addition to the industry principal at any one time. These individuals consisted of members of the industry scientist technical staff, although there was some participation from other parts of the company. Staffing of the university-based team included the university professor, two graduate students, and one post-doctoral scientist who was used during the end of the project. Contact between the two sub-projects was exclusively through the two co-investigators. Although there was some contact between the two graduate students at the university, and with the staff at the participating firm, the actual task assignments and work supervision were handled by the principal investigators at each of the particular sites.

Management Style. The management style adopted by the university scientist was fairly directive with his team. As he saw it the research design was formulated by the principal investigators, task assignments were made by them, and members of the team merely carried out their assigned duties. The university scientist saw as his primary responsibility making sure that the research was performed, and supervising and coordinating the work of team members. Compared to the work conducted at the firm site, the activities undertaken by the university-based team were much more theoretical and conceptual. These included identification of the research area, problem definition, statement of hypothesis, analyses, and report writing.

The industry scientist's management style was much more collegial and informal. He took great pains not to be labeled as a "manager" by his team members. In his words:

> Now, as a scientist which I still regard myself as one, I cannot afford to become . . . tainted as a manager . . . . I try very hard to preserve the scientist image which is why I am dressed the way I am and I'm not wearing a tie and vest.

Congruent with this perspective, there was considerably more use of team discussion and the industry scientist saw his primary managerial function as coordinating and evaluating the work of team members. In order to accomplish the intellectual task of the project, he saw his major functions being to encourage sound thinking by team members, to encourage team members to evaluate ideas, and of course to evaluate the ideas of team members.

Coordination

Coordination Within the Project. There was considerable interaction between team members associated with the two subprojects which was facilitated by the geographical propinquity of the two sites. Although one project was primarily theoretical, and the other project primarily experimental, there was a constant use of each subproject's results in the other subproject's activities. There were many lengthy phone calls between the two co-investigators as well as several meetings per year in which team members from the two subprojects interacted. Thus although the daily operations of the subprojects were quite independent of one another, the cross-fertilization of ideas and results was extensive. As described by the university principal:

> We have more phone conversations than face-to-face meetings. But, they are just about equally important now. Because there are a lot of questions that you can't resolve by phone. You have to sit down and with a pad in front of you, with a lot of paper in front of you, you know, to work it out.

Most of the face-to-face liaison meetings took place at the university, and there was no clear pattern in terms of who initiated the interactions. Overall coordination was helped by direct personnel transfer between the two subprojects. Some of the staff at the industry site were former students of the university professor. In addition a post-doctoral scientist was placed at the firm through the auspices of the university scientist.

Little of the coordination involved "joint management" in the true sense of that term. Theoretical work was largely done at the university; the experimental

work was situated at the industry site. There was some overlapping activity in the analysis of data which accounted for only about a quarter of total project activity.

In summary, inter-project coordination was facilitated in this research by the physical proximity of the two subprojects. The nature of interaction tended to be frequent, informal, and involving either face-to-face meetings or phone conversations. Although there was a fairly strict segregation of different parts of the projects between the two sites (experimental versus theoretical) there was extensive cross-fertilization of ideas and results.

Coordination and Reporting External to the Project. The industry researcher was under some fairly strenuous reporting obligations. Every three months he had to make a formal presentation on the project to an internal committee. This presentation was concerned more with schedule and finances rather than technical detail. The company's R&D management was aware of general progress of the project, but did not follow the project closely.

In addition to formal reporting requirements, there were requests for information about the project from both within and outside the company. One paper was presented at a professional society, and the industry principal investigator was asked to repeat his presentation at a major aeronautical company. Several dozen reprints of this presentation were sent to people within the company and elsewhere.

In a corresponding manner, there were more requests from outside the university than from within the university for reprints from the university scientist. In addition, the university researcher was obliged to keep his office of contract administration apprised of the progress of the project.

Benefits and Outcomes

Technical Outcomes. Two written reports were generated by the project, one a final report and the second a paper presented to a professional society. In addition, the work generated a data bank which will likely be used in subsequent projects. The prototype computer programs can be considered as a product of the project, as can the general method for drag determination that evolved from the work.

One set of intangible outcomes concerns both participants' greater appreciation and understanding of the other's research situation. The industry researcher achieved understanding of the difficulty in maintaining continuous research in the university with graduate students coming and going. One of the benefits perceived by the university researcher was more effective training of graduate students through their increased familiarity with industrial settings.

Knowledge Utilization. Both university and industry scientists felt the project had influenced the nature of research conducted in their settings. This included both changes in research topics and issues, and changes in research methods and procedures used. The university scientist felt that the research area was one that he would not have been involved in if it had not been for the cooperation of the company. He also felt that participation on the project tended to focus his research interest more on industrially relevant topics.

The industry scientist felt that several new projects were stimulated by this project's activities. The findings of the study indicated that the measurement techniques developed could be used in ongoing company R&D projects. It should be noted, of course, that the industry scientist's work had been primarily basic in nature, and one function that the IUCR grant served was to justify work of this type to his management. Many of the commercial benefits that would accrue to the company would not likely appear until well downstream. The university scientist shared his view that ultimately new products and processes would yield economic benefit to the company.

Personal Outcomes. Both university and industry researchers had quite modest expectations about the potential personal impact of participation in the project. The university professor felt that his participation in the IUCR project would have virtually no influence on promotion, salary, job assignments, or visibility within the university. He did feel that it would somewhat enhance his scientific prestige, but no more so than any other project in which he was involved.

In a similar manner the industry researcher was not overly optimistic about the personal benefits that would accrue to him from participation. He did feel that his prestige among peers in the larger scientific community would be enhanced, and that participation might have some effect on promotion, salary, and visibility to his management.

Both industry and university researchers were generally satisfied with the IUCR project. The university professor was particularly pleased with the opportunity to interact with researchers in industry on technical matters.

There was one issue about which the perceptions of the two co-investigators did not entirely mesh. While sympathetic to the problems of graduate training, the industry researcher expressed some concern about continuity in graduate student support, and expressed an interest in finding a way to ensure that research assistant help was of adequate quality. The university researcher, in turn, felt that the demands of the project were not entirely compatible with the training mission of the university, and expressed concern about certain inflexibilities in project scheduling and expectations. These difficulties should be placed in the con-

text of a larger general satisfaction with the IUCR project.

Policy Issues

The industry researcher endorsed the IUCR program as one worthwhile way to promote university-industry collaborative research. Both scientists urged that IUCR refrain from getting into research areas that were excessively applied in nature. It was felt that IUCR occupied a crucial niche in the research linkage between university and industry.

It was suggested that the government, or the NSF, could explore other ways of fostering university-industry research collaboration. The university scientists suggested that NSF perform some kind of brokering function, to link university and industry scientists pursuing similar lines of work. They also suggested the possibility of summer sabbatical experiences in industry, possibly with federal support.

There were comments about the level of funding available under the IUCR program, particularly from the industry side. The industrial co-investigator, and an R&D official in his company, commented that IUCR needs significant funding to achieve its goals. In summary, all participants gave at least a warm endorsement of the IUCR program and its various features.

Chapter 4

A PROJECT ON FILTRATION PROCESSES

Overview of Project and Participants

This research studied filtration processes in solids separation. The participants sought to increase the efficiency of their filtration system by developing a procedure for separation using smaller filter areas. The participating university was a state-supported university in the southwest; the participating firm a small chemical engineering firm in the northeast. The university researcher, a chemical engineer, had been on the faculty at the participating university for nearly 30 years. He had extensive consulting experience with industry, although most of his professional career had been spent in academic settings. Prominent in his field, he published extensively, and had received several NSF grants during the preceding five years. A member of the participating firm described the university professor in admiring terms:

> He is just quite big for an American. I am quite proud of an American being almost the top dog in this field. He honestly is.

The primary industry principal investigator had recently been awarded a Ph.D. in chemical engineering from the participating university (having studied under the university investigator) and had been with the participating firm only since the beginning of this IUCR project. Most of the experimental work was done by this individual. A second industry researcher, also a chemical engineer, had been with the participating firm for many years and had been informally involved in a prior NSF grant to the participating university.

The project itself was supported by a two-year grant from the NSF. Some funds were given to the company for salaries and equipment development. As of this writing the principal investigators had applied for another IUCR grant.

Prior Cross-Sector Collaboration

Prior University Activities. The participating university department had a long history of interaction with industry. Many faculty members had industrial work experience, and consulting or research relationships had been maintained with various industries. As a university respondent pointed out:

> There is, I would say, a very close relationship from industry to the Department . . . we try and have fundamental approaches leading ultimately to some [industrial] application.

Prior Firm Activities. In spite of its small size, the participating firm had a rich history of support to academic researchers through provision of funds, facilities, or staff expertise. A collaborative research project such as that funded by this IUCR grant was not an unusual experience for the firm. The industry principal investigators, however, had no prior experience in large-scale collaborative research with universities.

Initiation of the Collaborative Project

Preliminary Discussions/Work. Collaboration between members of the participating firm and the university researcher was of several years standing, but was somewhat convoluted in respect to roles and relationships among participants. Collaboration began serendipitously when the president of the participating firm attended one of the university professor's classes. This was a "short course" that was a frequent type of offering by the department. His firm was, at the time, developing a product closely related to research directions being pursued by the university scientist. The professor made a visit to the company, which began a long history of consulting and informal information exchange.

Early in this relationship the university scientist interested an undergraduate in pursuing a senior project in the filtration area. The research was rudimentary, as were the resources and equipment devoted to it (a modified eggbeater was part of the apparatus). The young man went on to work on his Ph.D. at the university and continued his filtration research under the tutelage of the university scientist. After receiving his degree the graduate student moved on to become the industry co-PI on this IUCR project. During the course of the grant, the industry scientist changed his status from temporary employee working on the project to permanent employee of the company.

Role of NSF IUCR Program. The university professor became aware of the IUCR program through NSF personnel. He recognized an opportunity to combine the work that he was doing with that of the participating firm and discussed the possibilities with the firm researchers, who were also enthusiastic about the possibilities.

While the university principal felt that his research in this general area would have gone on without NSF funding, the primary firm scientist felt that the character of the research in his company would have been significantly different. It was his feeling that he would

not in fact be employed by the firm in the absence of IUCR funding. Being of necessity profit-driven, they would not have been interested in research with no visible product and would have had no use for his academic talents. They would have developed their filter on a purely empirical basis and not concerned themselves with the scientific phenomena driving its effectiveness.

Application Process and Internal Negotiations. The IUCR grant was the second NSF grant awarded to these researchers for this project. Application and negotiation with NSF personnel were apparently left to the university researcher. He found the IUCR grant application process to be somewhat different from that of other NSF grants, primarily because of differences in NSF policy for industry and university equipment usage. Questions involving the use of equipment which had been provided to the company through this grant delayed the processing of the request for a second grant. Several requests from the NSF for budget revisions in the second grant request also contributed to the delay.

Project Management and Decision-Making

Team structure and roles in this project were somewhat unique in that the university scientist had served as the dissertation director for one of the firm principals and this project was in many ways a continuation of that recently completed dissertation. This created a bifurcated management and communication style within the project in which the firm principal worked independently, yet regularly sought the advice of the university principal in a manner quite different from the consultations sought by the other industry researchers. In addition, different research objectives between the industry and the university (i.e., production versus basic science orientations) were reflected in the principals' management styles.

Project Structure. Although there were many participants in this project, the bulk of the empirical work was conducted by one individual, the primary industry investigator. The working relationship between this industrial scientist and the university professor was initially very like that of Ph.D. candidate and dissertation advisor, and it was in fact an extension of that former relationship. As the project developed the industrial scientist took an increasingly independent role.

While the university team was formally composed of only the university professor and one graduate student, several other university faculty participated at one time or another in a rather fluid manner. There was no formal company team. Participating as needed were technicians, draftsmen, and a company design group for instrument development. The secondary principal played a dominant role at first and then diminished his part as the primary principal gained experience.

Management Style. Researchers participated equally in project implementation. Goals were established and broad scheduling accomplished with the participation of all team members, and most researchers seem to have worked independently within the context of those decisions.

Management style within each team, however, appears to have differed somewhat. While the university researcher delegated authority for scheduling and work allocation to a research scientist on his team, the primary company researcher worked autonomously. A second level of management appears to have existed within the firm in that this researcher was required to submit regular progress reports to the secondary firm investigator. This may have been a pro forma type of reporting, however, and receipt of these reports is the only function, in addition to some administrative tasks, evident for the secondary principal.

It is interesting to note that the university researcher's perception of his most important managerial function was that of evaluating the work of team members, while the primary industry researcher indicated dissemination of results as his most important managerial function. Clearly, contrasting managerial styles among principals in this project reflect the basic-versus-applied science schism historically exhibited in industry/university interactions, as well as an extended student/advisor relationship between the principals.

Coordination

Coordination within this project appears to have been more a function of ad hoc advice and consultation than of scheduled interaction. This may have been due in part to the student/advisor relationship enjoyed by two of the principals and partly a reflection of the primary industry researcher's autonomy.

Coordination Within the Project. Coordination between the two principals was frequent and ad hoc in nature. When the firm scientist wished to discuss data analyses or interpretation, the university professor made himself available for advice. The firm scientist had relatives whom he visited in the university community and this also contributed to frequent informal meetings. Consultations were apparently confined to general and theoretical matters, specific decisions and procedural problems being handled by the firm scientist working alone. In the words of the industry principal:

> . . . he [the university principal] knows in general what I am doing, what is the scheduling, but he has no way of knowing about the specific things.
>
> . . . initially, there is an interface, and then less interface, and usually you see him at the end of each

phase, to tell him . . . what happened, and to discuss with him in detail what happened in the last three months or something.

Communication within the project as a whole was frequent and fluid, particularly in terms of presentation of results. As described by the university researcher:

> . . . we're in contact back and forth with papers. I've had some of the manuscripts [which were] written up there first and then sent down to me to redo. I've done some manuscripts and sent them up there for them to look over and add their thoughts to. And we send copies of experimental work we do up to them to look at and they send work down to us.

Coordination and Reporting External to the Project. Any coordination external to the project which may have existed was certainly not formalized. The company involved was small (less than 150 employees) and an atmosphere of open communication seemed to be the norm.

Benefits and Outcomes

Technical Outcomes. All principals agreed that the most important technical outcome of this research was knowledge gained in the field of filtration research. In particular, they learned fundamentals related to the equipment, data necessary for evaluation, design methods, limitations on equipment use, and optimization techniques.

The increment in knowledge achieved by this research was important to all concerned, primarily because of the underdeveloped nature of this field of inquiry. The primary firm researcher had experienced a great deal of difficulty in his dissertation research because of the dearth of literature in the field; the large number of publications that resulted from this project have apparently contributed a great deal to that knowledge base.

An equally important outcome of this research was the shift in research interest observed in the participating firm. This project has apparently stimulated an R&D capability within the company and an increased interest in a scientific approach to product development. In the words of the principal firm scientist:

> One thing is, the attitude of the people in here has changed completely. Before, I mean, they just worked on empiricism.

Knowledge Utilization. Information resulting from this project has been widely distributed and has significantly affected present and future firm operations. The university principal presented a large number of lectures and short courses on the subject, resulting in over a hundred requests for information, and had frequent communication with Japanese and European researchers and businessmen interested in the process. The results of the project have had a tremendous impact on the participating company's operations. Project results have influenced product design and have become an integral part of testing routines. Both co-investigators believe that there is more to be learned in this area and expect some rather stiff competition from Europe and Japan.

Personal Outcomes. Both principal investigators anticipated increased prestige among colleagues and in the larger scientific community as a result of the project. The primary industry researcher gained a great deal through this research: increased visibility in the scientific community; increased research opportunities within his firm; and his permanent position with the firm itself. The university investigator was given a prominent award by a professional society in recognition of his work.

Policy Issues

All researchers were enthusiastic about opportunities for joint research afforded by the IUCR program and welcomed such collaboration as long overdue. University personnel in particular were encouraged by what they perceived as a growing interest on the part of industry in such research. As one of the university resondents put it:

> . . . the attitude of industry, large and small, is beginning to change quite substantially. A few years ago—lets say ten years ago—government funding was just going gangbusters. And if you talked with the industry, American industry, about cooperative work with the universities, that was just a foreign idea. Today I think the industry is beginning to say, if it's going to be done, we're going to help fund it.

The industry/university collaboration was particularly important to these researchers in light of what they perceived as an abundance of industry engineers lacking training in the fundamentals of their fields. The university scientist in particular felt that the "classic problem of not having the various links in a chain necessary to solve problems" lends itself very easily to solutions through collaborative research and, at the same time, collaboration softens the rather polarized viewpoints of industry and universities regarding basic and applied research. As the university researcher put it:

> I have a very difficult time differentiating between the practical and the theoretical myself. I think you might find that a century ago that you would have had a great deal of difficulty in seeing [a researcher] as a mathematician or an engineer or a chemist or physicist or what because they looked at problems in their entirety and went and tried to solve those things that were needed to be solved, but [they] were really being philosophical.

University and firm personnel alike saw the IUCR program as a vehicle for reducing this apparent schism in research interests and were particularly gratified by the changes in attitude and performance which took place in both the participating firm and the university as a result of their collaboration. A member of the participating firm put the analysis in more graphic terms:

> The theory of universities is, you know, like a dream. It is idealistic and over here we bring it down to reality because you are not going to run it. The customer is going to run it, who bought it, and if the damn thing does not work they are going to give it back. . . . There is a gap there; it is being narrowed down a hell of a lot by the university/industry approach.

The university researcher had some observations on the status of U. S. industrial research. It was his feeling that corporate emphasis on short-term profits effectively stymies long-range research:

> . . . if you are aimed at short-term results, you will never support long-term education research. . . . there's no way, if a company is trying to optimize their profits . . . that you can justify any kind of investment in education when the results come out six or seven years later.

Moreover, he felt that more rapid industrial development would be possible in this country were there more continuity and coordination in university research pursuits. He believed that a balance between group and individual undertakings, where a continuity of effort is maintained over time, is more conducive to advances in scientific research and, what is certainly as important, training of young researchers to fill the shoes of their older predecessors.

While not related to IUCR per se, both researchers addressed one issue: the threat of foreign technological competition. Each felt that the Japanese and Europeans were moving much more rapidly and astutely in exploiting this research area. The university scientist commented on the ease with which his foreign colleagues were able to obtain resources to pursue technology development. One of the firm principals expressed apprehension about his company's developments being copied and exploited by foreign visitors.

Chapter 5

A PROJECT ON ELECTRO CHEMISTRY

Overview of Project and Participants

This research project was a theoretical study in the area of electro chemistry. It focused on the interface between metal surfaces in ionic solutions, highlighting problems of the stability of chemical products. The participating university was a large public institution in the southeast; the participating firm was the west coast R&D lab of a Fortune 500 manufacturer of information processing equipment. The university participant, a chemist in his late 40's, began his professional career with a three-year stint in industry. He had since been employed in academic settings for 22 years, fourteen of them at this university. Since coming to the university he had consulted with several small firms. The university department was not among the top ten in its field although this faculty member was well-known, had received several research grants, and had published extensively.

The firm researcher was a physicist, also in his late 40's. He had spent eight years in academic positions before joining the firm as a mid level research scientist, a position he had held for thirteen years. He was also quite active in his field in terms of awards, publications, and memberships in professional organizations.

The project was supported by a three-year grant. One half of the grant funds were subcontracted to the firm to cover the salary of a postdoctorate, a small part of the firm researcher's salary, and corporate computer usage.

Prior Cross-Sector Collaboration

Prior University Activities. The university had no on-going contacts with this firm prior to the IUCR grant. However, as a part of the local government's efforts to attract high-technology industries, the university was attempting to increase collaborative training and research activities with industry in general.

There was some on-going interaction between the two researchers prior to the initiation of this project. They had met about eight years ago at a professional symposium where both were invited speakers. This led to correspondence around mutual research interests and discussions several times a year at professional meetings. In addition, the university scientist had served as a consultant and lecturer for the firm prior to this grant.

Prior Firm Activities. The participating company has a long history of interaction with universities. However, their only prior contact with this institution was through the association of the two investigators. The firm scientist began his career in academia and since joining the firm has held the position of visiting scientist at several universities, but not at the cooperating university.

Initiation of the Collaborative Project

Preliminary Discussions/Work. This grant was a continuation and expansion of a small joint project funded by another government agency. About a year prior to the submission of the NSF proposal, the university researcher was asked to submit a proposal to that program. He responded with a joint project with the firm scientist and they received a small grant which primarily covered travel costs. When this program was eliminated they were forced to look for another source of funds.

Role of NSF IUCR Program. A colleague of the firm scientist, who had himself submitted an IUCR grant proposal, suggested they do the same. The university scientist had also performed research in this general area, under one of several previous NSF grants. In effect the IUCR program allowed these two researchers to continue and expand a previously initiated project.

Both researchers felt the project could have been implemented, on some level, even without NSF support. However, they also agreed that project scope and priority would have been diminished. The professor was unsure if the university research office—which had a small budget for project "seed money"—would have contributed funding, but felt that they might have been interested because of the collaborative nature of the project. He did feel that the firm would have provided some support. He cautioned, however, that travel funds and thus face-to-face communication would have been severely limited, a definite disadvantage.

The industry researcher noted that "such a research project probably might have occurred anyway." However, he also felt that travel funds would have been limited and there would have been no funding of a postdoctorate (their costs makes them relatively rare at the firm). Also of importance to him, without NSF salary support the project would have been assigned a lower priority in the firm and thus his involvement would have been limited.

The university scientist went one step further, noting that the firm's sophisticated computer facilities

were essential to this project. He further believed he could not have performed this particular piece of research without the firm scientist because, " . . . he had one part of the technique, and I had the other part of the technique." The firm scientist felt that working in parallel would have forced them into competition. In summary, although research might have been undertaken on some level, possibly with firm support, it would not have resulted in the major effort that occurred.

Application Process and Internal Negotiations. There were substantial differences from normal practice in the processing of the grant application and award for both university and firm. While the processing of the NSF grant proposal per se was routine within the university, the contract to the firm was "a totally different and new thing" and a separate approval process, requiring five levels of administrative signatures, was involved. There were complex legal negotiations with the firm for six months after NSF funding, which focused not only on contract details but also on the protection of proprietary information, since university team members would be working on the firm site. One result was that the firm researcher was without a postdoctorate for the first six months of project operations. One important negotiating issue was the need to clarify computer usage by the university team members. The contracts administrator for the firm noted that their relative unfamiliarity with the IUCR program contributed to the delay because of the need to resolve differences between the NSF/firm positions on several legal issues.

Although there were complex logistics connected with this project, from the perspective of the firm they were congruent with past experience with universities. For example, the firm research manager noted that they had negotiated with one university for "years" and never resolved issues such as patents and intellectual property rights.

Project Management and Decision-Making

Project Structure. The organizational structure of this project was very complex. There were two research teams operating concurrently at different sites several thousand miles apart, each with a different supervisor, and each with changing membership which included graduate students and postdoctorates.

The university team included the professor and one postdoctorate the first year, with a second postdoctorate added the second year. During the third year of the project the professor replaced the postdoctorates with two graduate students because his funds for personnel were depleted.

The industry team consisted of the firm scientist and one postdoctorate each year of the project. The postdoctorates, however, changed each year. There was also a third team member, who was a professor on a six-month sabbatical. He was, however, not formally part of the NSF grant. In effect, each of the principal scientists selected and directed his own 1-3 man team, with each team operating independently of the other.

Management Style. In terms of management duties the university researcher identified his primary functions as the selection, supervision and coordination of team activities with emphasis on encouraging idea generation from team members and colleagues. Reflecting the cross-disciplinary nature of the project, the translation of ideas from one discipline to another was also perceived as an important function. Administrative duties including personnel decisions and the selection of equipment occupied less of his time. He considered his team members experienced researchers, noting that almost all of the postdoctorates had published and that the graduate students were older and had worked in the field.

The firm scientist displayed a similar management style for his team. He considered team supervision and task evaluation his most important management functions along with eliciting new ideas. He too was involved in all aspects of his teams' research activity, with administrative duties occupying only a small percentage of his time. Problem identification and definition were among his top priorities along with selection of methods, formulation of hypotheses, data analysis, and report writing. In describing the differences in their roles the firm scientist said:

> I guess what the division of labor comes down to . . . [the university researcher] has . . . done [the] analytical work, and I have . . . [tested] the theory on the computer.

While both researchers emphasized the collaborative nature of their work there were some differences in their perceptions of the amount of the research effort which required sharing of work or joint management.

Coordination

Coordination Within the Project. The distance between the two sites, the relative independence of the teams, and the frequent changes in team personnel might have produced major logistical problems in a project of this magnitude. However, several factors facilitated intraproject communication, one of which is the fact that long distance collaboration is common in this field. As the university scientist put it, "A lot of our research is done by mail or over the phone." In a sense, the only equipment required was a phone and access to computer facilities, both of which were readily available on both sites. More importantly, this was a continuation of a previous project involving the two men. These were two colleagues who had known each

other for more than eight years and exhibited much mutual respect and admiration.

Communication between the two teams was channeled through the two principal investigators who communicated heavily by phone, with the number of calls ranging from several times a week to several times a month depending on the stage of the research. In addition to phone calls and letters, each researcher visited the other's site once a year for a period of one to three weeks. Several additional meetings per year were planned to coincide with the researchers' attendance at professional conferences.

While communication among team members at each site appeared quite open and flexible, there was little contact between the postdoctorates at the two sites. They never visited the other site; they never met their counterparts. Their contact with the other site was restricted to discussions with the other principal investigator. There was one exception to this pattern. One of the university-based postdoctorates visited the firm for several weeks during the first year of the project to use the computer. While he interacted frequently with the firm scientist, he met few other staff members. According to the firm researcher, "he was more interested in using the computer." While travel costs influenced this lack of interaction, the pattern tends to reinforce the relative independence of the two teams.

Coordination and Reporting External to the Project. Communication between the researchers and their respective organizations varied in scope and style. For the university researcher there were no formal reporting requirements outside of his normal obligation to publish in the scientific literature. He did, however, discuss the project with one dean and several colleagues in his department who were involved in related research. He also corresponded with a number of colleagues in the U. S. and Europe, including two of his former team members.

The firm researcher, on the other hand, was required to submit progress reports covering all of his on-going research projects. These reports were in turn incorporated into his department's report, which was circulated throughout the research lab and to top administrators. A research division manager who "had long thought that NSF was never going to support anything for us," was acutely interested in project activities. On-going communication with other parts of the firm was primarily focused on computer center staff because "we regularly had problems with the program."

The divisional R&D staff's primary contact with the project was their initial sign-off on the contract. However, there was another research group within the lab which performed similar research and with whom there was some interaction. In fact a member of this group, who met the academic researcher during one of his early site visits, went on to collaborate with him on another joint project. The firm researcher also corresponded with academic colleagues concerning this and related research.

Benefits and Outcomes

Technical Outcomes. As expected this research project has generated a number of scientific articles, technical reports, and several internal firm reports. More specific prototype devices could not be discussed because of proprietary information restraints. Both researchers felt that advances in scientific knowledge were an important outcome. In their opinion the research has led to the development of better theories to explain certain phenomena as well as the identification of new areas for further research.

Knowledge Utilization. One indication of the interest generated by this research was the number of requests for information. The university professor has distributed approximately 500 reprints of project-related articles, and according to him the publications have been cited frequently in the literature. Similarly, the firm researcher received about 100 outside requests for reprints of project-related articles, about one-fourth of them from industrial researchers. He was also chosen to chair a special meeting of his professional association on this research area.

There were limited internal requests for project information. However, both researchers felt that the project had influenced research directions and methods within their respective organizations. The university professor began a second joint project with another researcher from the participating firm. This second project involved experiments suggested by the theoretical results of the IUCR grant. In addition the professor encouraged another faculty member to initiate related research with other industrial participation. Finally, a former post-doctoral team member returned to the university as a faculty member, and continued to work in this area. The university scientist predicted that this project will encourage other faculty members to undertake research in this area.

Because of its theoretical focus the professor did not forsee the project having an impact on product development in the firm. Nor did he think it would enhance the quality of firm research. In his words the company:

> is one of the best laboratories in the country . . . relative to what's happening there, I think it . . . [this project] is a very small contribution.

In fact, the industry scientist felt quite differently. He saw the project as partly responsible for a change in the company's research focus in that the firm decided to concentrate on electro chemical research. In his view:

> [this project] is certainly a part of the reason that electro chemistry has been recognized as an important scientific discipline in this laboratory.

In terms of follow-on research he emphasized that without this project the professor and his colleague would probably never have met and initiated the second joint project. This grant was also viewed as having improved the firm capability to deal with government regulations and with university scientists. Contract negotiations for the second joint project were much smoother.

Personal Outcomes. As a full professor with tenure, the project had minimal impact on the university scientist's standing within his organization. However, he did feel it enhanced his prestige in the larger scientific community and might lead to opportunities to lecture at other universities. In support of this view, the firm scientist felt the recognition given to the university professor would enhance the reputation of several recently developed Ph.D. science programs at the university.

For the firm scientist, participation in this project positively affected his prestige and visibility within his organization as well as in the larger scientific community. As mentioned previously he was selected to chair a major professional association meeting devoted to this research area. The fact that this was the first NSF grant in his lab increased his visibility to upper level management. More important, the grant increased management's confidence in the value of basic research. He pointed out:

> I think that an industrial laboratory has difficulty assessing the value of a basic research program . . . they have a great deal of difficulty because the only justification is the outside recognition . . . receiving the grant is a form of recognition.

The firm researcher is confident that this project will increase his freedom to choose future research projects, and he credits this project with changing his own research direction and approach. A member of the lab director's staff added that such projects fulfill a basic need of their scientists "to be known to their colleagues outside, just as if they were in the university." Both university and firm researchers were very positive in their overall evaluation of the project.

Policy Issues

Several firm administrators sounded a note of caution regarding the future of cross-sector collaboration. They perceived the current trend among universities to restrict patents and intellectual property rights as impeding scientific inquiry. They pointed to long delays in undertaking some joint research, as well as some projects which had to be cancelled because agreements could not be reached. In their opinion, such problems could severely restrict or eliminate future industrial funding of university research. In the words of one:

> If we are competing with universities as far as talents of people and resources for doing research, then why should we finance our competition?

In spite of this warning this company had a history of extensive research interaction with universities, and clearly valued its relations with them.

Neither university nor industry scientist felt that joint projects would push university research too far into applied areas. For the university professor, industry was seen as providing direction for fundamental research, which he believed "has to have a purpose." The industry respondents indicated that their need to protect proprietary information would guard the possibility of involving "outsiders" in development work.

Both the university and industry researchers emphasized the role of the IUCR program in encouraging joint research activity. For the firm this project also appeared to have improved their relations with the government, NSF in particular. There was some concern expressed, however, regarding the changes in program funding and guidelines. One company administrator expressed the hope that such programs could be "stabilized" since both results as well as cross-sector relationships take time.

Chapter 6

A PROJECT ON NUCLEAR SCIENCE

Overview of Project and Participants

The focus of this research was the development of nuclear science instrumentation for improving carbon 14 dating techniques. The work funded by this IUCR grant was a part of continuing research performed in a center at the participating university.

The participating firm was a small manufacturer of analytical instrumentation; the participating university was a private university in the east. The university researcher, a physicist, had been on the faculty of the university for nearly 20 years, although he had some prior work experience in industry. He published extensively and had received other NSF grants.

The industry researcher, also a physicist, was chief scientist and chairman of the board of the participating firm. He too had published extensively and, prior to forming the participating firm, was an adjunct faculty member at the participating university. He had been involved in one other NSF grant during the past five years.

The project itself was supported by two one-year grants from the NSF which were funded consecutively. No funds were given to the industry participant.

Prior Cross-Sector Collaboration

Prior relationships between the research principals consisted of a long-term professional acquaintance and collaboration in research conducted through the nuclear physics laboratory at the participating university. This IUCR project was an extension of that continuing relationship.

Prior University Activities. The university was apparently not a stranger to industry-university research collaboration in the field of nuclear physics, and prior work between the principals involved in this project was the result of their connection with the nuclear physics lab at the university.

Prior Firm Activities. Following his departure from the university faculty to form his business, the industry scientist frequently participated in continuing research at the university, meeting with his university colleagues up to several times a month. The participating university is apparently the only university with which this firm conducts collaborative research.

Initiation of the Collaborative Project

Preliminary Discussions/Work. The research conducted under this IUCR grant was designed to more fully exploit the potential of new techniques resulting from ongoing research, primarily through large-scale testing of new concepts on existing university apparatus. Original measurements demonstrated the feasibility of the techniques, and also indicated the need for both extended measurement and modified equipment.

Role of NSF IUCR Program. The researchers first heard of the IUCR program through a program announcement. They talked to an NSF program manager about their findings and the need for further work and he suggested they apply for an IUCR grant. Both principals felt that the work conducted under the ensuing IUCR grant would not have been possible without NSF funding, particularly the improved instrumentation that was supported. The firm researcher in particular pointed out that, while many other researchers had attempted to replicate or extend their findings, no significant work had emerged due to lack of appropriate equipment. Since neither the firm nor the university could have afforded the improved instrumentation, both principals felt that their collaboration would have collapsed without NSF support. In the words of the university scientist:

> I think, without the funding from the Industry/University Cooperative Program . . . our whole work in this area would have substantially declined . . . . This program has only been in operation since 1977 and in my view and in the view of a lot of people, it has been spectacularly successful.

Application Process and Internal Negotiations. There were no apparent problems or difficulties associated with application for the grant for either principal. The issue of internal negotiations in the case of the industry researcher is moot since he is the owner of the firm. The university investigator could see no difference between the application process for this project and other government grants.

Project Management and Decision-Making

Project Structure. Participation in the project was very fluid and open, and many scientists not officially part of the project were involved. This was a direct result of the project being embedded in a larger research center in the university. Project participants were essentially center participants. When the expertise of another scientist was required for the IUCR project, it was available:

> Typically we had a lot of people . . . generally we would bring in somebody who was a specialist for the particular

task we wanted to do. When we worked on geology we had a guy from another university who was a geologist . . . and he was very helpful in pointing our noses in the right direction. We did not try to become a very closed society. We made it as open as possible.

While each of the two teams usually consisted of only two members at any one time, it is difficult to estimate total participation in this research. Many participants were from other universities, although some were from the participating firm.

Management Style. Management of the grant was congruent with the existing structure of the research center. Within that center management, both co-investigators considered supervision of team members to be their most important managerial function. Both used a direct supervisory style in assigning and evaluating the work of other team members. The university professor in particular had extensive personal involvement in all phases of the research from conceptualization to publishing of results.

Coordination

The structure of the research was such that coordination both internal and external to the project occurred on a fairly regular basis. Each new set of measurements required a new set of procedures, possible equipment modification, and input of expertise external to the project. Internal and external communication lines were fluid and open at all times.

Coordination Within the Project. While the majority of experimentation was carried out at the participating university, a great deal of communication was conducted by phone and letter between the principal investigators. Coordination was clearly aided by the prior relationship between the principals. The university P.I. described the process as follows:

> He was actually a member of the lab for a number of years prior to his forming his company and I think our relationship then and now is very similar. When a major decision had to be made—is made or had to be made—I would either phone him or write to him or whatever and make sure that he agreed with the point of view that I had.

Coordination and Reporting External to the Project. Communication external to the project was also frequent and was usually initiated by the principal investigators. A variety of researchers in the field were intermittantly consulted about project issues. The nature of this interaction ranged from consultation and advice to "bench level" work. Anyone who directly participated in a series of measurements was a team member and a co-author of any subsequent publication.

Benefits and Outcomes

Because the work performed under this grant was one ingredient of a continuing research effort conducted at the university center for the past several years, it was difficult to attribute specific benefits and outcomes to this project alone. Nonetheless, several tangible and intangible products were seen as resulting from the work.

Technical Outcomes. The outcomes of this research were significant from both a scientific and a commercial standpoint. Several new products and techniques were developed which were of great commercial value both in the U. S. and in other countries. This was particularly gratifying to the industry scientist:

> . . . a company of this size cannot afford to be in the business of doing research for research's sake. Otherwise, you are taking the shareholder's money and spending it on things that are not appropriate. You have got to end up with a product and you have got to end up with a product which is not inordinately long down the road. You can't build something that will be good in the year 2100.

During the course of the grant, 29 papers were accepted for publication from participating scientists. Important to both principals were the advances in the field gained through this research. Both principal investigators and one other senior researcher were awarded a prize for contributions in the research area. According to the university investigator:

> . . . when the new equipment actually gets installed, it is going to have an important impact on the whole mass spectrometry program . . . . There are now 22—at least 22 laboratories similar to this one—some of them smaller—that have gotten into this field since we began. So it is a brand new field and it has excited a lot of people.

Knowledge Utilization. By virtue of its multidisciplinary application, transfer of knowledge was virtually inherent to this research. The salience of this function was enhanced by the activities of the university scientist, who was particularly interested in involving additional participants and disseminating information about the research. Many colloquia, seminars, and invited papers were presented during the course of the research. Since the beginning of the research, articles on the project have appeared in every issue of the Annual Report of the President published by the participating university. Team members have been recruited from across the country as well as Canada.

Future work is anticipated both within the participating university and in collaboration with other companies. The team currently anticipates work with another university department on ocean measurements and presently has approximately 50 requests for car-

bon dating, including one for an artifact of major theological significance.

The results of this research had considerable impact on both the direction of future research and research methodology both within the participating university and firm, and in the field in general. The increased sensitivity levels achieved with the new techniques have expanded both the realm of possible application and the methods for obtaining measurements. In addition, the project also affected what the university principal perceived as the bias of his university toward "pure research." As the university P.I. succinctly phrased it:

> There is always this sort of snobbism at the university about doing "pure research" as opposed to applied research and I think that a number of people that had that view—and there probably were some even in this laboratory—have actually changed their minds about it as a result of this particular project.

Personal Outcomes. Both principal investigators anticipated substantial personal benefit from their collaboration, particularly in terms of increased prestige. The firm principal, as the head of a small business, was particularly sensitive to this:

> . . . you tend to, I think, enhance your image and certainly the image of the company to outsiders when you are collaborating, have joint efforts. It sort of puts you in the IBM class rather than in the Joe Blow's Electroplating House class.

Policy Issues

Both principals were very supportive of the NSF role in fostering cooperative research in general and were especially articulate about their perceptions of the particular contributions of the IUCR program. As the university researcher said:

> The National Science Foundation has demonstrated already . . . that they can play a useful role in stimulating research, applied research in industry and to do it in a way that industry and universities collaborate is a very—to me at least, a very sound, positive way to spend Federal funds.

The firm scientist in particular was enthusiastic about the transfer of knowledge between industry and universities:

> There is a tremendous wealth of expertise in the universities which I think can help the United States tremendously and part of the difficulty is to get it out of the universities. It seems to me that . . . this should be the goal of these programs, getting the expertise which is in the universities into the society.

It was his feeling that the IUCR program had gone a long way towards achieving that goal and he made two suggestions for improved program management. He suggested that NSF take an active role in matching university and firm researchers of like interests to collaborative undertakings. His primary concern was for those researchers, particularly industry researchers, who may have had no prior experience with NSF or with collaborative research, and consequently may not be temperamentally or organizationally equipped to generate such research on their own. He felt that under the present system, in which funding is frequently the result of an agency's familiarity with the work of a particular researcher, potentially valuable contributions are "lost in the shuffle."

The firm principal was somewhat concerned about the potential for dilution of the research effort in the absence of careful management. He felt that university-industry collaborations, dealing as they do with high calibre scientists of somewhat "prima donna-ish" temperament, have tremendous potential for going astray. He suggested more structured guidelines for the conduct of the research and closer monitoring on the part of the NSF.

The university researcher was most enthusiastic about the potential of the IUCR program in terms of "cross-channel" or multi-disciplinary research and in providing what he termed "risk money" for more innovative research efforts.

> And one of the things I saw the IUCR funds doing is . . . something a little more inventive and maybe even a little more risk-taking and I guess, if you are not prepared to take some risks in basic research, then you are probably not going to get really inventive, innovative [results].

Chapter 7

A PROJECT ON POLYMER CHEMISTRY

Overview of Project and Participants

This project focused on the dynamics and properties of polymers. It combined theoretical and experimental activities in the exploration of molecular motions and their relationship to mechanical properties. The participating firm was a Fortune 500 manufacturer of chemicals and related products; the participating university was a medium-sized private institution in the midwest. The two sites were less than five miles apart.

The university researcher, a chemist in his late 40's, had spent his entire professional career in academic institutions. The last eighteen years were spent at the participating university, interspersed with visiting professorships at several other institutions. Although the university department was not ranked in the top ten in its field, this researcher was active in terms of publications and research grants.

The industry researcher, also a chemist in his mid-forties, had been employed at the participating firm since receiving his doctorate 20 years ago. Currently a senior-level scientist in the firm, he was prominent in his field of research and had published extensively. He had been responsible for developing a laboratory procedure which was internationally known and used.

The Industry University Cooperative Research (IUCR) project was supported by a three-year grant; no funds were given to the firm.

Prior Cross-Sector Collaboration

Prior University Activities. This university had a history of collaboration with industry on many levels, which included involvement in several large-scale research programs with Fortune 500 corporations such as the participating firm. The university professor's department played an active role in many of these projects.

The principal researchers were close personal friends as well as colleagues. They had met during their graduate training 20 years ago and had collaborated on research and published together periodically since that time. The university scientist, while he was a postdoctorate, had helped the firm scientist with his dissertation research. When they moved to the same city after their academic training, they continued collaborating. This eventually resulted in the university professor receiving several unrestricted grants from the firm. This work was his only formal contact with industry, although he had received several research grants from non-industry sources including the NSF.

Prior Firm Activity. The participating firm was a pioneer in the field of joint research programs and had established several large-scale collaborative programs with major universities over the last ten years. During the IUCR project the firm scientist was an adjunct professor at the university and a frequent participant in seminar activities of the participating department.

Initiation of the Collaborative Project

Preliminary Discussions/Work. The university scientist credits the firm researcher with introducing him to this area of research. In his words:

> . . . He'd basically been talking to me about polymers and plastics for years over cocktails, and finally we found a problem that as a theorist I couldn't resist, because I could solve it exactly . . . . It became interesting, and I started to work on it over several years more and more, and now it's basically the only area [that I work in].

The IUCR project was a continuation and expansion of work initiated by the university scientist under several unrestricted grants from the firm. For several years prior to the NSF grant the professor and several postdoctorates had been supported for work in this research area. The firm scientist had collaborated on an informal basis in these activities.

The firm scientist confirmed that he had attempted to interest his colleague in this research area for a number of years and that as part of that effort his firm had given several unrestricted grants to the professor. He portrayed the university researcher's work as "fulfilling a real need" for the firm since they had no theorist in this area on staff. There were however several company scientists, including the industry co-investigator, engaged in related experimental work.

Role of NSF IUCR Program. The need for additional project staff, specifically another experimentalist to work with the firm researcher, prompted the application to NSF. The university scientist first learned of the IUCR program from an article in a professional journal, and after encouragement from an NSF program manager, a joint proposal was submitted.

The department chairman was unsure if this particular project would have been initiated without the "catalyst" of NSF involvement. Both project scientists felt their previous collaboration would have continued; although as the firm scientist explained:

> . . . it's a little hard to disentangle what work's being done for this project and what work would occur whether the project existed or not.

The industry researcher did feel that the NSF grant, by requiring formal goals and specific industry input, had sharpened the research focus and increased the firm's influence over project direction.

Application Process and Internal Negotiations. The university scientist and his department chairman agreed that the approval process for this grant was fairly routine. Similarly, it was part of the "normal machinery" for the firm and required only one signature. The difference according to the firm researcher was that the grant did not allow his company to impose the kind of tight scheduling or sense of urgency that typically guided industrial research. In effect, "the timing would be more relaxed."

Project Management and Decision-Making

Project Structure. The organizational structure of this project reflected the division of labor into theoretical and experimental work. There were essentially two independent teams, one at each site, each supervised solely by the principal investigator at that site.

The university professor supervised one postdoctorate. In addition a new faculty member, who had worked for two summers on the grant during a visiting professorship, planned to resume work with the university team. However, he was not officially a part of the NSF project.

The industry team consisted of the firm scientist and one postdoctorate, who although officially on staff at the university, spent the majority of his time at the company. The principal investigators had agreed on this arrangement for the postdoctorate so that " . . . if he decided that he wanted an academic career, his credentials would be more impressive . . . ." Several members of the company staff contributed peripherally to the project. That is, they shared equipment with the project team and "were doing work which impinges, in one way or another, on what we're doing [in the NSF project]." They occasionally attended project team meetings.

Management Style. Both principal researchers emphasized the "team approach" in their work. The university scientist saw the identification and supervision of personnel as two of his primary managerial functions but portrayed a relaxed supervisory style. He explained:

> In principle [the firm scientist] and I decide [work priorities and assignments]. In practice its discussed by everyone and we've always had agreement . . .

Another team member expanded on this thought:

> . . . It is a very informal operation . . . there is no structure . . . we just do it and discuss things, argue and fight and debate, and, you know, try to find a way . . . [task assignment] may be at three in the morning when I'm over [the university researcher's] house for dinner . . .

The university scientist was involved in all aspects of the research activity at his site. Reflecting his theoretical bent he highlighted the formulation of the research questions as "the most important thing I'm doing." The translation of research ideas from one discipline to another was seen as another major task. He spent minimal time performing administrative and budgetary tasks.

The firm scientist saw himself and the two university faculty members as responsible for determining research direction, setting priorities, and assigning tasks, with the two postdoctorates primarily involved in task execution. His approach to team management emphasized collegiality:

> I tend to treat all the people that are working with me as collaborators and colleagues rather than subordinates. That's just my style . . . we give the postdoctorates lots of flexibility and lots of room . . . .

His most important managerial functions were the coordination and evaluation of his team's work. Based on the university team's limited background in polymers his primary intellectual task was the translation of ideas from one discipline to another. Since the firm did not receive NSF funding he had no involvement in administrative and budgetary tasks. In comparing the roles of the two teams he saw the company team as having exclusive responsibility for experimental work although, on occasion, he participated in defining theoretical problems. The university professor agreed that the two teams were "doing quite different things." Little if any of the research involved overlapping of work or joint management.

Coordination

Coordination Within the Project. The proximity of the two sites, the informal managerial styles of the principal researchers, and their close personal and professional relationships facilitated frequent professional as well as social communication between and within the teams. The co-investigators interacted several times a week, either by phone or in person. Meetings were held at either site or in their homes. (They lived within several blocks of each other.) Often the firm scientist stopped to chat with the university team when he attended weekly departmental seminars. The postdoctorate assigned to the firm was the only person who worked and maintained an office at both sites.

The nature of the research also dictated frequent interaction, as each team's activities had an impact on the work of the other. The firm scientist described this symbiotic relationship:

> . . . [we] try to put into the theoretical work the physical basis of what our experimental results show. And similarly . . . when we are interpreting our results, we try to use the models that are being generated by the theory people . . . .

Initial team meetings were informal gatherings, and according to the firm scientist they were called, "when I've got something which is well enough defined to put it on the blackboard and talk about it." Later, formal joint team meetings twice a month at alternating sites were conducted, "so that everybody is aware of what everyone else is doing." The increase in team size, such as the addition of another faculty member and the input from other firm staff, precipitated this decision.

Coordination and Reporting External to the Project. Organizational reporting requirements regarding project activities were minimal for both researchers. Outside of his obligations to publish in the scientific literature, the university professor was required to submit reports only to NSF. However, he routinely sent copies of the annual NSF report to his department chairman and to the university research office. There was also ongoing communication with faculty in his and other departments. One colleague who planned to conduct related research was invited to attend team meetings.

The industry scientist made a concerted effort to coordinate his research activities with others in the field. His required monthly progress report kept management abreast of relevant project activities. He also circulated preprints of project publications to potentially interested colleagues and maintained an on-going dialogue with a staff member in another division. Several members of his own staff interacted frequently with team members around related research. Contacts external to the firm included the principal researchers on another IUCR grant, one of whom had been a postdoctorate (supported by the company) at the university. The project was also discussed with the staff of another Fortune 500 company who were performing similar research.

Benefits and Outcomes

Technical Outcomes. As expected, the project generated a number of scientific articles and internal reports. While the university scientist predicted that project activities might eventually yield a variety of proprietary outcomes, including improvements in instrumentation and manufacturing processes, the firm scientist was less optimistic that anything of commercial value would soon result.

Both researchers emphasized intellectual products and advances in basic scientific knowledge, in particular the development of a new experimental procedure by the firm-based postdoctorate. Both described this procedure as a significant achievement in the field and predicted that it would be widely used. This outcome was the result of pursuing a line of inquiry that serendipitously emerged during the course of the project. The firm scientist noted that it was the flexibility in task assignment and supervisory style that led to this achievement by allowing a postdoctorate to pursue research activities not directly related to project goals. Another team member noted, "its been so productive because people feel free to try out new ideas and suggestions."

Other benefits listed by the co-investigators included improved morale and collaboration between the university department and the firm, which according to the firm researcher had "increased the whole productivity of the theoretical effort." Another benefit to the company was the opportunity to "preview" prospective employees.

Knowledge Utilization. Both researchers made a conscious effort to disseminate project results. Although the university professor received only about ten requests for information from colleagues in his and two other departments, he had discussed project results at departmental seminars and had begun planning interdepartmental seminars. He had also received inquiries regarding the collaborative nature of the grant from two colleagues who were exploring research possibilities with other firms. External requests numbered well over 100 and included contacts with other Fortune 500 firms, a French university and several government agencies and labs. Both researchers had presented their results at national and international meetings. They had also visited another firm engaged in this line of work, to discuss the project.

The university investigator felt these efforts had "raised scientific curiosity." His department chairman went even further. In his opinion the team's enthusiasm over this project had:

> . . . been partially instrumental in reactivating, redirecting and re-enthusing some of the other faculty . . . and certainly faculty enthusiasm does generate student enthusiasm.

The department chairman's interest in this project was, in part, a reflection of his 26 years at a Fortune 500 firm where he moved from bench level scientist to director of R&D before returning to academia. He was sensitive to the problems as well as the potential benefits and was in his words:

> . . . deeply involved in the business of attempting to formulate on various levels an industrial-academic program involving [this] university . . . .

His interest certainly added to the department's positive response to the project.

Although only one other professor had begun research in this area, both the academic investigator and his department chairman predicted that others would

follow. There was also the former project postdoctorate, now on faculty, who planned to continue his research, either as a part of the NSF grant (a renewal proposal was planned) or on his own. In terms of changes in research methods, the university scientist pointed to the expected use of the new experimental procedure by both industry and university researchers. The academic researcher felt strongly that he would never have moved into this research area without the encouragement of his firm collaborator.

The firm scientist received few formal requests for information from within his company and only one from a non-R&D division. However, a top R&D official explained that there was wide dissemination of internal project reports to "a fairly large segment of the company's technical community including the top administrative committee." In terms of external users, the industry co-investigator received several requests for information from academic theorists in this area with whom he regularly corresponded. A significant member of the audience was another Fortune 500 firm, which had a strong working relationship and exchanged information on an on-going basis with the productivity firm. These liaison activities resulted in the other company contributing samples which were essential to the team's laboratory work.

Another team member was also involved in dissemination activities. The firm-based postdoctorate had presented his research results at a major professional conference and had assisted another university in implementing his new experimental procedure.

The IUCR grant did not generate any new research in the firm. However, the company had implemented the new experimental procedure and the firm scientist planned to continue his own research in this area. He further explained that these experiments applied only indirectly to the company's current research focus, which had changed since this project began. He believed there was "probably more interest and excitement" at the other company with which they exchanged information because it continued to be involved in this specific research area.

Personal Outcomes. For the university scientist the project's impact centered on his increased visibility to upper level administrators and his enhanced prestige in the larger scientific community. In addition, a former team member's participation in the project had led directly to his faculty appointment at the university. The project had also broadened this team member's research interests by exposing him to "challenging" research problems, and had sensitized him to industry needs. However, he remained committed to an academic career, preferring the freedom it offered.

For the firm scientist the project had "no immediate payoff" because it was "so far removed from a commercially important result." More intangible benefits included some increased prestige in the scientific community, more visibility to upper level management and continued company support for his work in this area.

The firm-based postdoctorate listed several personal benefits including access to quality equipment and the opportunity to work with a prominent scientist who had facilitated the introduction of his new procedure to the scientific community. This team member had not been approached by the firm regarding future employment because of a hiring freeze. This did not concern him because he planned to pursue an academic career.

Although the firm scientist appeared more restrained in his assessment of the project's overall impact, both principal investigators expressed satisfaction with the grant.

Policy Issues

Respondents from both sectors agreed that IUCR-type programs played a critical role in facilitating collaborative activities. The university scientist pointed out that such programs help convince academicians that:

> . . . they don't automatically become tainted because they're working with people in industry . . . you don't lose your precious academic freedom.

The department chairman added that these collaborations improved university science by sensitizing university researchers to industrial concerns.

Both sides offered some suggestions for IUCR-type programs. The university respondents emphasized the need to choose projects that are both on the "cutting edge" of science and have commercial opportunity. They also felt that federal funds should remain "seed money" and not become a substitute for industrial research funds. One top administrator praised this evaluation effort because it would demonstrate to skeptics in both sectors:

> . . . where these things have worked, what the elements are that made them work, what the elements were . . . [that contributed] to failures . . . .

The firm R&D director encouraged the government to continue offering incentives to private industry such as the liberalization of patent policy and offered some prescriptive wisdom for firms new to this activity. In his view, companies must commit internal staff resources to these joint projects, otherwise they cannot develop the commercial potential of research results. The company scientist added that staff involvement in such projects must be more than "a part-time assignment"; it must be part of the researchers' on-going responsibilities.

Chapter 8

A PROJECT ON LIMNOLOGY AND FISHERIES BIOLOGY

Overview of Projects and Participants

This project was a field study of the marine environment and those factors which would optimize the growth and survival of a species of fish. The participating university was a large public institution in the northwest; the academic department was ranked in the top ten in its field. The participating firm was a Fortune 500 forest products company with an interest in aquiculture. The two organizations were approximately 28 miles apart, although the experimental work was performed at an island field site which was accessible primarily by ferry. This site was some distance from both the university and the company.

The university researcher, a zoologist in his early 40's, had spent his entire professional career in academia, the last ten years at this university. He was an associate professor, active in publishing and professional associations, and successful in obtaining research grants. Other university staff who were involved included another associate professor, who functioned as a co-investigator, and a staff biologist.

The industry researcher, also a zoologist in his 40's, had been employed at his curent firm ever since receiving his Ph.D. nine years ago from the participating university. At the time of this project he was a research section manager and had authored publications in the field. During the last year of the grant, after data collection was completed, the industry researcher changed companies. This departure was significant in that the firm's involvement with the project essentially ended at that point.

The project was supported by a three-year grant from NSF. The firm received a small subcontract for equipment and some laboratory work.

Prior Cross-Sector Collaboration

Prior University Activities. The university and the department were involved in a range of collaborative activities with industry, including several other IUCR grants. As noted above, the firm scientist had received his graduate training from the collaborating university department and his work was known to the university professor. The two principal investigators met during a visit by the industry researcher to the university to discuss potential research projects, when they were introduced by a department colleague. Two of the three university team members had prior industrial contacts in the form of contract research projects and consulting arrangements, but not with this company.

Prior Firm Activity. The participating firm was involved in several collaborative activities with universities, including another IUCR grant with a different department at this university. The company was active in consulting relationships, contract research projects and student intern programs. The firm scientist himself was involved in other research projects with faculty members in the department. In fact, one of the "standards of performance" by which the firm scientist was evaluated was how well he worked with universities in long-term research.

Initiation of the Collaborative Project

Preliminary Discussions/Work. The research institute staff at the university had been engaged in this area of study for more than ten years and had, according to the university scientist, collected "a tremendous amount of descriptive data." However, there was a perceived need to examine "more basic, mechanistic questions." After their introduction the two scientists discussed general research issues, which led to the idea of a joint project. The period between these initial discussions and the final NSF submission spanned some eighteen months.

Role of the NSF/IUCR Program. At about the time of the preliminary discussions, the university professor saw a brochure on the IUCR program. He then asked a colleague to obtain further information during an upcoming trip to NSF. Once this information was received it stimulated a tangible proposal to NSF. The university professor was very familiar with the general NSF application process, having received several awards in the five years prior to this grant.

According to the university professor this project probably would not have been implemented in its present form without the IUCR program. However, he would have submitted portions of the project to another NSF division (without the company involvement) or to another federal or state agency.

The industry scientist, on the other hand, stated that his company would have definitely not been involved in the project without some outside support. He explained:

> The work was too long range in scope for our business clients to fund. Our work was only applied and therefore shorter term with results having immediate impact on business economics.

The university scientist agreed that the firm would not have assumed full funding for this project. According to him:

> . . . it was of a size . . . probably beyond the norm that they would fund, it was more than they usually allocate for such undertakings unless it is in-house research . . . their in-house research doesn't have as many basic elements in it . . . .

Application Process and Internal Negotiations. The university professor indicated that the university approval process was fairly routine, including the subcontract to the firm. It required only the signatures of his dean and the director of grants and contracts. In contrast, the NSF application process required several proposal revisions to scale down the work to reduce costs, although the university scientist felt this process was helpful and served to focus the research effort.

The industry scientist indicated that there were some differences in the approval process in his firm. Although he did not outline the specifics, apparently the long-term and fundamental nature of the research required a different decision-making process, with approval based primarily on the scientist's ability to secure some outside funding. However, only one level of approval was required and there were no stated problems associated with securing this agreement.

Project Management and Decision-Making

Project Structure. There was essentially one research team, staffed by university faculty and students, with the industry group acting as consultants.The university team consisted of four persons: the principal investigator; another research associate professor who served as co-principal investigator; a staff biologist; and one graduate student. The three faculty/staff members had worked together on a number of research projects prior to the IUCR grant. The industry group consisted of a senior scientist and several technicians.

Management Style. The university scientist described his group as working as a team with "tremendous rapport among us." He was involved in all managerial and research functions but saw his primary responsibilities as evaluating and disseminating the team's work and deciding resource priorities. He placed a major emphasis on soliciting new ideas from his team. He also served as the grant's administrator, "taking care of the checkbook," watching the schedule, and keeping the team to stated project objectives. In his words:

> I was active in all facets of the research . . . . I am one of the people actually in the lab and in the field . . . .

The industry scientist did not elaborate on his relationship with the firm technicians involved in the project, although it was implied that he worked closely with them in the design, selection, purchase and installation of the sophisticated audio-visual equipment system required for lab and field experiments. He listed his primary managerial role as a liaison between the university team and his company. Neither the company scientist nor the company technicians were involved in the experimental work. The firm scientist did have some administrative duties, presumably in relation to the subcontractual arrangement.

In comparing the roles of the two groups the university investigator saw the firm staff functioning primarily as "technical experts," with the firm scientist having input in the conceptualization of the project and evaluating the relevancy of certain studies to the firm's needs. In his words:

> We would seek his input as a researcher and a person with tremendous background in the practical aspects of aquiculture to see if he thought that [the proposed experiment] had meaning to the firm.

Reflecting this division of labor, both investigators felt that very little of the research effort involved sharing of the work or joint management.

Coordination

Coordination Within the Project. Communication and coordination of effort between the two groups reflected their different roles in the project. The university team members interacted frequently among themselves around this and other projects. In contrast, their contact with company staff was limited to three or four weeks a year. During these times interaction included a fairly intense mixture of phone calls, letters and memos, with the university team initiating most of the contacts. There were additional discussions with the firm scientist when he visited the university on other business.

Meetings were held at both sites; however, the graduate student was the only university team member who worked at both sites. During the initial phase of the project, he visited the firm several times to use specialized equipment for some experiments. However, his trips ceased when the team ended their work in that area.

The firm scientist characterized the limited contact as follows:

> The principal collaborative work involved the development of technology needed to record predator-prey behavior [at the field site] using the TV and video tape system. Meetings and discussions were held to scope the project, then the system was purchased and put together and demonstrated to university personnel at [our] headquarters. After agreement the system was installed by [our] technicians at the [field site].

It should be recalled that neither the university nor the firm was the primary work site. The experimental

work took place at a wooded field site on an island located several hours away from both organizations.

Coordination and Reporting External to the Project. This project apparently did not require extensive coordination between organizations. There were no formal reporting requirements for the university scientist outside of his normal obligation to publish in the scientific literature. He did, however, discuss the project informally with institute colleagues who were engaged in related research. There was also continual interaction with colleagues at other universities in both the U. S. and Canada which had fisheries programs. The firm researcher was required to submit reports to the corporate R&D division manager, although he felt that top R&D officials were only minimally aware of the project. Central R&D staff provided the audio-visual and electronic equipment needed in the experimental work.

Benefits and Outcomes

Technical Outcomes. As of this writing the project is still in the data reduction stage, although it has generated one published article with two additional ones in for review. A newspaper in the town where the field experiments were conducted, and the university alumni association, have both published articles on the project. Both researchers felt that the advance in general scientific knowledge was a major outcome. The university scientist strongly believed that this and related research will ultimately aid the government as well as private industry in the revitalization of the fisheries industry.

Knowledge Utilization. Because few publications had been completed, formal requests for information were limited. The university scientist did receive several calls based on the local newspaper article and the alumni publication. The university professor believed that the project would stimulate other academic scientists to conduct research in this area, particularly work which would couple laboratory and field methods. Eventually he hoped to have an impact not only on the research agenda and methods of the department, but also the activities of related state and federal agencies. He saw the project as having minimal short-term impact on the firm in terms of tangible benefits.

The industry scientist had received several internal and external requests for information on the project, the majority of them focusing on the technical nature of the research. He felt it was too early to specify the project's impact on the company's research operations. However, he did predict less reluctance on the part of company scientists to engage in joint research with universities. The industry scientist left the firm before data analysis was completed, which essentially ended his company's participation. This certainly blunted the project's overall impact on the firm.

Although both researchers expressed overall satisfaction with the technical results, each would have liked more frequent interaction between the two groups. The university scientist felt that more industry participation in data acquisition and analysis would have expanded his understanding of the industrial R&D process. In his words:

> . . . I'd become more aware of how they approach a problem, what they forsee as research needs and how they go about performing them . . . we would learn . . . how to cooperate better, how to be more aware of their needs . . . .

The firm scientist, although impressed with the enthusiasm of the university staff, expressed some frustration with his own limited role:

> I am dissatisfied that I didn't have time to participate in project activities, conduct my own research, etc. I had little discretionary time to pursue these areas. Also I lacked time to interact with university staff members in brainstorming ideas, concepts and data analysis.

Personal Outcomes. The university scientist, based on the success of this project, was very optimistic about its potential impact on his professional career in terms of promotion, salary, prestige, and visibility to upper level university administrators. The firm scientist had benefited from this project in several ways prior to leaving the firm. He described his experience as follows:

> I was able to leverage more research for dollars spent by [the firm's R&D division] . . . . Visibility among R&D staff was increased due to this accomplishment . . . .

The firm scientist left the firm in order to manage a major production aquiculture operation in another state. Presumably the firm scientist was able to leverage his role on this project into his subsequent position with the other firm.

Policy Issues

Both scientists were enthusiastic in their support of the IUCR program. The university scientist felt "it is probably one of the most important things that NSF could do because [our] future is probably the future of industry." The firm scientist agreed:

> . . . this project represents an outstanding example of accomplishing long-range research which is absolutely necessary but which is difficult to fund by a developing business. This is precisely where the Federal Government funding agencies should contribute.

Given that the company's interest in the project essentially terminated with the industry scientist's departure, the importance of the "project chairperson" role in a firm seems obvious. Not surprisingly, the industry scientist hoped that such cooperative programs could be

undertaken in his new company. The industry researcher was so positive on university-industry cooperation that he suggested that government could enhance these relationships "by requiring university research to have an industrial sponsor."

The university scientist had several suggestions for IUCR program management, including the possible expansion of topic areas and the inclusion of more industrial scientists in the review process. He also thought NSF should sponsor more "sociological" research on the impact of technological change on industry personnel. In his view:

> This country has a lot of problems . . . industry is in trouble . . . [NSF] ought to come at it from more than just a technical end of it or the pure science end of it . . . .

Finally, the academic researcher offered some guidance for overall government activities in this area. He suggested workshops to encourage broader communication between universities and firms. These workshops would be used to identify research areas and, more important, to teach university scientists to think as industrial scientists and vice versa. He felt strongly that this would improve the coordination of joint efforts.

Chapter 9

A PROJECT ON NON-DESTRUCTIVE TESTING

Overview of Project and Participants

This research project explored methods for the three-dimensional display of various materials and structures for non-destructive testing as well as medical diagnosis. The participating firm was a Fortune 500 company in the aerospace industry. The participating university was a large, private west coast institution; the department ranked in the top ten in the field.

There were two university researchers involved in this grant. The senior investigator, an engineer, had been on the faculty at the university since receiving his doctorate there twenty years ago. This researcher was prominent and very active in professional associations, had served as a delegate to international meetings, had received several prestigious awards, and had numerous publications. The university co-principal investigator, also an engineer, had received his doctorate from the same university fifteen years ago and had spent his entire academic career there.

There were several industry researchers involved in this project. The senior researcher, a physicist, had been employed at his company since receiving the doctorate approximately twenty years ago. He had received his master's degree from the participating university. He had never worked in an academic setting, and his career had been spent entirely in industrial research and development with increasing management responsibilities over the last ten years. During the second year of the IUCR grant he accepted a management position in a product division of the firm and subsequently severed formal ties with the project.

The firm researcher who assumed the role of principal investigator at that time had received his doctorate in engineering from the participating university seven years ago and had since been employed in industry. He had joined the firm five years prior to the project.

The project was supported by a three-year grant from the NSF. Approximately one-half of the funds were subcontracted to the firm for staff salaries and the production of materials.

Prior Cross-Sector Collaboration

Prior University Activities. Faculty members of the department were involved in a variety of formal and informal collaborative programs with industry. These activities included consultation and contract research projects, and extended to faculty start-ups of high-technology firms. Of particular note was an external graduate degree program in which courses were relayed to industrial sites by closed circuit television. The university had also received a number of other IUCR grants. Both university researchers had fairly extensive contacts with industry prior to the IUCR project, including student placement activities, consultancies and contract research projects with both large corporations and small, high-technology firms. The senior university researcher had been a consultant to the participating firm.

Prior Firm Activities. The firm was heavily involved in collaborative projects with a number of universities throughout the country, including the participating institution. Activities included contract research, cooperative education and training programs and membership in several university-industrial affiliates programs, including one sponsored by this university. The firm was also involved in IUCR projects with several other institutions.

The initial industry principal investigator's prior contacts with the university were limited to his work as a graduate student. Although he and the primary university researcher generally knew of each other via professional meetings, they had never formally met before the initiation of the IUCR grant. However both university co-principal investigators knew the second firm researcher, who had been a doctoral student under one of them before he was employed by the firm.

Initiation of the Collaborative Project

Preliminary Discussions/Work. Both university and industry investigators had previously performed research in this general area but had focused on different applications of the specific techniques. The primary university scientist had received several prior NSF grants, and an NSF program manager who knew both he and the industry scientist suggested they contact each other to discuss mutual research interests. The firm researcher took the lead in phoning the university scientist, and subsequent discussions over approximately a year's time led to the submission of an IUCR proposal.

Role of NSF IUCR Program. The NSF program manager was responsible for alerting these scientists to the existence of the IUCR program and its funding guidelines, and they agreed that he was the primary catalyst for the initiation of the collaborative effort. According to one of the university scientists:

> . . . this never would have . . . happened without his suggestion . . . . I mean, it is quite a natural thing to happen but it never would have happened without the catalyst that he provided.

The senior firm scientist agreed:

> I think it really took . . . the impetus of NSF . . . to sort of bring it to a head . . . . It was in the area more of just an interest . . . we probably would not have found a mechanism for interacting with [the university], other than this program.

In addition to NSF's interpersonal brokering role, both university and industry researchers testified to the importance of NSF funding per se. The university would not have provided funding, and the firm researcher doubted that such fundamental research would have been approved by his firm without the lever of NSF support. He explained:

> You know, if this thing has enough merit to it so that the government will put a little bit of money into it, they, our management, looks with more favor on it, too.

Application Process and Internal Negotiations. There was some initial discussion within the university regarding the structure of the firm's involvement. However, once a subcontract arrangement had been agreed upon, the approval of the grant was fairly routine. After the grant was awarded, discussion on implementing the subcontract "went reasonably smooth too." Similarly the firm scientist described an uneventful approval process in his company. Again the contract with the university, although not a problem, involved "a different kind of paperwork" than other research contracts.

Project Management and Decision-Making

Project Structure. This project involved a fairly large and complex effort, with two independent teams, one at each site, each jointly supervised by two or three persons. Core project staff numbered ten persons, including university faculty, graduate students, and firm management and research staff. Complicating matters further, there were three distinct subprojects and the firm team leader was replaced during the second year of project operations.

The university team consisted of two senior faculty members who functioned as co-principal investigators, a junior faculty member who joined the team during the first year of the grant, and two Ph.D. students. Staffing at the industry site included the principal scientist and three staff researchers, one of whom became principal investigator in the project's second year. In addition other company staff participated in the project "on a part-time basis."

Management Style. Team member roles and functions reflected the division of research activity into three related subprojects, each of which focused on a different approach to the three-dimensional display of images. The division of labor was based on the specialized equipment available at each site as well as the need to identify appropriate research for the two graduate students. Two projects were conducted at the university, and each one served as a dissertation topic. The third project was implemented by the industry team.

Each university co-investigator served as the dissertation chairman for one of the graduate students, while the third faculty member served on both students' committees. Task assignment and supervision of the two subprojects was carried out within the context of weekly meetings with each student and semi-weekly joint team meetings. There was also informal interaction:

> we meet in halls or there are some new results and there is a knock on the door . . . .

The senior university scientist saw his primary managerial role as the supervision, evaluation and dissemination of team work. His primary intellectual tasks focused on soliciting and evaluating ideas of team members and others. Because of the students' need for self direction in their dissertation research, he had minimal involvement in the collection or production of data but played a major role in problem definition, formulation of hypotheses and research design. (Literature review tasks were performed primarily by the firm team using their computerized information retrieval system.) As the grantee of record this faculty member also performed the major administrative tasks.

Management responsibilities were also shared among firm team staff. The initial industry principal investigator served primarily as a project administrator, and was not actually involved in research tasks. In his words:

> . . . my having had a management position, I am a little bit unusual in this sense in that my role in this project has been more one of guiding it than doing the work myself . . . .

Within this context he described his primary tasks as supervising team work, serving as liaison between the team and the firm, disseminating project results, and encouraging team members to contribute and evaluate new ideas.

Day-to-day technical direction of the industrial research activities was provided by another team member, a former student of the senior university researcher. He had been involved in the project from its inception, including early discussions with university staff about grant submission. In fact he was chosen by the senior researcher because of his ties to the university staff. The academic researchers were concerned about carving out a meaningful role for the graduate students. In their words:

> We were concerned that bringing in two new Ph.D. students beginning their work in this area, they might somehow be left behind by the [firm] people . . . .
>
> We were afraid that perhaps [the firm] would somehow pick up with these ideas and be able to move with them much faster than [the students] . . . and kind of leave us behind so to speak.

The choice of a former university graduate student as de facto director of the industry part of the research eliminated these concerns:

> Knowing this person as well as I did, this removed all of my concern about possible conflicts between us . . . in fact, all of those concerns turned out to be unfounded and things have worked out just beautifully.

Because of these prior understandings, the change in official firm principal investigator was not viewed as a particularly disruptive event. As the initial industry investigator explained:

> . . . I have had management responsibility for a number of [other] projects in the course of this one so by leaving it, I probably had less impact on the program than, say, a more typical principal investigator would have had.

Once specific research problems had been identified and the work divided into three subprojects, the two teams worked independently. The university professors supervised their students' dissertation research, with some overlap in functions; the two firm scientists managed different aspects of the firm team's activities.

Coordination

Coordination Within the Project. An informal atmosphere prevailed among the university team members, while the industry team members related on a more formal basis. The differences in the ages and positions among the company team (i.e., bench level scientist versus senior level R&D manager) in a sense dictated these internal relationships.

The university and industry investigators met alone only to discuss grant administration, while the bulk of intra-project communication was via joint team meetings held every two weeks at the university. Firm security procedures and the need to accommodate faculty schedules made the university a more convenient site for these joint meetings. Meetings were held at the firm only when company equipment was needed for presentations. All team members from both institutions attended these joint team meetings and an open, informal atmosphere prevailed. According to the senior firm manager:

> We sat around the table as equals and we reviewed things. One or another would, perhaps, make an informal presentation of their work . . . .

The meetings generally focused on current team activities and planning for future work. While a norm of equality prevailed at these meetings, the senior university scientist felt that his team had more influence on the firm's work than vice-versa, primarily because of the firm's position as a subcontractor. The meetings were supplemented with some phone communication between teams, but as the senior firm manager explained:

> When you have a regular meeting scheduled, you tend to save up things for that and that was the case here.

Although no member of either team was based at the other site, both teams utilized each other's research facilities and equipment. The computer room at the firm became an informal meeting place for both teams. As one team member described the milieu:

> Everybody came through there and worked there, so there was a lot of interaction.

This on-going, informal communication was facilitated by the proximity of the two sites (a few miles apart) as well as the ties between team members discussed earlier. Involvement in the joint meetings played a crucial role in the project, and participation was valued by team members. For example, even after the initial industrial principal left the project, he continued to attend team meetings to stay in touch with the research.

Coordination and Reporting External to the Project. Formal reporting requirements were minimal for both teams. The senior university scientist sent annual reports to NSF with copies to the university grants office. His co-investigator coordinated their work with another university department in which he had a joint appointment. There was also some exchange of information between one of the graduate students and a staff member in a government lab who was engaged in similar research.

The senior firm scientist reported project progress in regular contract review meetings. However, top officials in the company were only generally aware of the project and their interest was focused on its NSF sponsorship. The firm scientist did interact frequently with engineering and production staff who were interested in the project's potential applicability to their work.

Benefits and Outcomes

Technical Outcomes. While the project was still in progress at the time of this writing, it had already produced several technical results such as published articles, internal reports, and computer programs. In addition, the two dissertations should be complete at the end of the project. Neither senior scientist saw

commercial product development as a likely potential outcome. As a firm manager explained:

> We are perhaps not a typical industrial research lab in that sense, in that we are probably more interested in developing basic technology than we are in supporting manufacturing or production or any of those things.

Less tangible benefits resulting from the project were the general expansion in technical knowledge and the enhancement of graduate student training. According to the university professor:

> . . . from the university's point of view, we have carried out one of our most important missions, which is the education of graduate students . . . .

The firm scientist added to this:

> I think it is very beneficial for students in their training period to get to know industrial scientists or technologists in order to see the balanced point of view for themselves and to see that their faculty advisors interact with people in industry . . . .

One of the graduate students felt working on this project had changed his perception of industrial research, and he noted that he was "impressed with the freedom firm scientists had to pursue their research interests," and found it "rewarding to come up with something new, which is of use." Although his career plans were unclear he intended to continue his industrial contacts.

Another less tangible benefit described by both scientists was the confidence gained that such joint projects could work. According to the firm scientist, whose previous experiences with such projects had not been entirely positive:

> . . . I think that has probably been, to my mind, the single most important thing that has come out of it, the fact that we could work together sort of as equals and that we developed a respect for each other.

The senior university scientist agreed that he too would be "less hesitant to enter into something like this in the future . . . ."

Knowledge Utilization. Dissemination efforts were only recently implemented. During the first two years of project operations the investigators had informally discussed project activities with a small number of colleagues at professional meetings or visitors to the sites. However, the senior university scientist explained that most faculty were not really aware of the project. The firm manager, on the other hand, had received information requests from the research lab and product division staff who were interested in the application of project results to their individual efforts. In addition he had discussed IUCR program requirements with several colleagues.

The first formal presentation of results occurred in the third year of project operations and consisted of a jointly planned two-day seminar conducted at a professional association meeting. However, the two teams made separate presentations and as a result there was little recognition of the collaborative nature of the research. Both investigators felt their team's work had been well received and expected to receive inquiries regarding the presentations. In addition, they intended to involve potential users within each organization in the evaluation of new research techniques developed in the project.

The two teams differed in their perceptions of the project's influence on internal research activities. The senior university scientist explained that the project's impact was minimal because faculty in the university had been working in this general research area for some time and would continue to do so. However, for several team members this was the first time they had been involved in a project with potential application to another discipline, and the senior university scientist suggested it might lead him to future research in that discipline.

The senior industry scientist listed one follow-on research project with another government agency as a direct outgrowth of this research. He further felt that the project had exposed his staff to new research methods, provided a focus for some of the company's in-house work and encouraged the lab to perform more creative, less applied research.

Personal Outcomes. For the university team personal benefits revolved around increased prestige in the scientific community. This was also true for the initial firm scientist, even though he had left R&D for a management position in a product division. All investigators expressed great personal satisfaction with the results of the research, especially the success of the collaboration.

Policy Issues

Respondents from both sectors offered comments on program management issues. The senior university scientist felt strongly that academic institutions should serve as the grantee to assure them of equal status with the firms. He further encouraged the use of three-year versus two-year grants to assure continuity of support for graduate students. He also suggested that such projects would be more productive if the expertise of the co-investigators was complementary rather than overlapping. In terms of problem areas he mentioned the high overhead rates of both universities and firms, which in his case had forced him to reduce the level of effort to produce a reasonable budget. Finally he hoped that the dual program review process could be shortened.

All respondents agreed that joint activities should be encouraged by the Federal Government. Suggestions included government scheduled meetings to encourage discussion between the two sectors, as well as government co-purchase of advanced equipment.

The senior university scientist offered a final note regarding the increasing industrial interest in these activities:

> . . . and the surprising thing to me is that . . . I am not going out and beating the bushes for industrial support . . . . Rather industries are approaching me . . . .

Chapter 10

A PROJECT ON CHEMICAL ENGINEERING

Overview of Project and Participants

This project addressed fundamental questions in chemical engineering regarding the conversion of carbon-based substances to liquid fuels. Utilizing slurry bed and packed bed conversion methods, the study made a comparison of results achieved by the two processes under similar reaction conditions. The participating university was an eastern private institution, which is among the top 10 in the field of engineering; the participating firm was a Fortune 500 energy company.

The university investigator, a chemical engineer, had been with the participating university for over 30 years. He had done a considerable amount of consulting in industry, had published extensively, and had received several other NSF grants. Two doctoral candidates also participated in the project.

Over the course of the research two different industry principal investigators were involved, one of whom was forced to leave the project before it was fully implemented. Both were chemical engineers, they had spent the majority of their professional careers in industrial settings, and most of their time had been spent in R&D. One had joined the participating firm approximately ten years ago and the other had been with the firm for over 30 years. Neither had any previous NSF grant experience.

The project was supported by a three-year grant, still in effect at the time of this writing. No grant funds were distributed to the industry participant.

Prior Cross-Sector Collaboration

Prior University Activities. The university participant described prior industry/university relationships as a "sort of a matrix of interaction" of apparently many years standing, although neither he nor the graduate students in the project had been involved in prior industry/university research collaboration per se. In his words:

> . . . we are constantly in touch with people in industry. We see them at meetings and the staff as a whole does considerable consulting with industry. We have a lot of [industry] interviewers in and out.

The university principal investigator had been a consultant to industry for over 30 years, and it was through his consulting relationship with the participating company that he met his industrial collaborators. He commented on the difficulty of doing work with industry without some prior contact. Other prior contacts among university team members included a doctoral student who had been employed by the firm for a summer prior to the project, and another professor who was a thesis advisor to one of this project's doctoral students and who had previously worked at the participating company.

Prior Firm Activities. The university professor's perception of close, ongoing industry/university relationships was shared by staff of the participating company. The firm principal characterized the consulting relationships in particular as frequent and intense:

> . . . they are pretty close to us . . . they have been consulting for a few years, three or four or five years, . . . and we bare our souls over that time to each other and that sort of relationship may be important.

Although the project participants had not been personally involved in any formal Industry/University Cooperative Research (IUCR) collaborations, it is possible that other programs within the firm had. In addition, the industry researcher was quite familiar with the university principal's work and reputation in his field.

Initiation of the Collaborative Project

Preliminary Discussions/Work. To the extent that the comparative nature of the research demanded parallel analyses, the genesis of this collaboration was a fortuitous match of available apparatus and mutual interest. The project represented the continuation of past research on the part of both principals, in what constituted an important and fundamental question in chemical reaction engineering. The initial industry investigator had been doing exploratory work under a non-NSF government contract, and had constructed apparatus and developed procedural techniques necessary for one aspect of the experimentation. The university researcher had constructed equipment under prior, non-NSF government support for another phase of the research.

Role of NSF IUCR Program. Although the university scientist had received several NSF grants in the past, neither principal investigator had prior experience with the IUCR program. The industry researcher had learned about the IUCR program through a colleague at his firm; the university investigator through a program announcement.

It is interesting to note that while the university professor indicated he would not have done the research without NSF funding, the firm researchers felt that the research would probably have been done in any case—perhaps as an in-house, non-collaborative project. This is apparently a growing field within the company, with an increasing number of staff involved in experimentation in this area. It was felt that "someone" in the firm would have done the work, with or without NSF funding. It will be recalled that the firm received no NSF funds in this project.

Application Process and Internal Negotiations. Because of industry interest in this subject area, the principal investigators had no apparent difficulty in acquiring company support for the proposal:

> . . . in this kind of research, if you feel it is important for the company, we can get resources very quickly . . . if it wasn't very important for the company, we normally may not have even gotten into it . . . . We would take our resources and put them in something else.

The university researcher's negotiations with his university were equally uneventful, due no doubt to his reputation and his years on the faculty. The three required levels of approval were "essentially pro forma."

The university investigator apparently played an active role in presenting the proposal to company management. He experienced no opposition to the proposed research, but some time was spent in working through logistics and answering concerns about proprietary rights and benefits to the company. He described the following scenario:

> But [the firm managers] asked themselves, "What do we get out of it? Why should we do this?"
>
> And they know that I am a good investigator and that I will do high-quality work so they are interested in seeing that it will work out . . . . But then we have to work through the [company] organization to be sure that they are happy with it, that they are not going to lose any proprietary rights.
>
> . . . . So in this sense, as I say, you have got to try to "sell it" to the [company] organization . . . . And then in turn, this means that all the justification of it is a three-party operation rather than a two-party operation. It is nothing insurmountable. It just takes more time, that is all.

Both principals were concerned about the time and effort involved in the NSF application process. The university researcher, who had prior NSF experience, found IUCR procedures more complicated, largely because of the three-party rather than two-party involvement (industry, university and NSF rather than the university/NSF involvement he was familiar with) but also because of two changes in program managers at NSF during the course of the application. The changes required three separate presentations of essentially the same material, a procedure which the university principal described as a "long, tortuous process."

The university principal did not see these delays as insurmountable but certainly time-consuming. However, in the case of the initial industry co-investigator, the delays effectively removed him from the project. By the time the grant was awarded, his talents were required in another project. Fortunately another company researcher, who had built other appropriate apparatus and had time available, was willing to take his place.

Project Management and Decision-Making

Project Structure. Management *per se* was not a particularly salient activity in this project. The bifurcated nature of the research demanded largely independent efforts on the part of all participants. In addition, team size did not lend itself to, nor for that matter require, formal management procedures.

Although there were three principal investigators and two doctoral candidates involved during the course of this project, the "team" effectively consisted of only three members: a firm principal investigator, a university principal investigator and a doctoral student. As was previously mentioned, the time delay in processing the grant caused the initial industry principal investigator to be replaced by another scientist. The initial doctoral student was also replaced at some point in the project.

To a significant degree the two subprojects operated autonomously. The doctoral students worked, for the most part, at the university under direct supervision of the university professor. The firm scientist conducted his portion of the research at his company, presumably on his own. Apparently there was no cross-team supervision between the two subprojects.

Management Style. To the extent that there was a management structure, it rested with the university principal, who perceived his role as intellectual rather than supervisory. The firm principal denied any significant management responsibilities:

> . . . I was not involved . . . in any of the program management . . . . It was really a program in which I felt a . . . major portion was done by [the participating university] . . . . I would say that we did basically play a technical role in the comparative aspects of the area with which we were concerned but other than that we didn't play any role.

Many of the management responsibilities involving the university principal were of an informal, mediating role:

> The chief investigator has to take time. It takes time to get a research plan organized, find out what each per-

son wants to do and can do. We also need to work out some alternative plans in the event that the first set of studies do not go as expected . . . .

Many project decisions were reached through mutual discussion between the two scientists, with both principals expressing a high degree of involvement starting from the problem definition stage of the research and continuing through the analysis of results. Differences in perception of personal involvement existed only in collection and production of data and selection of equipment. Selection of equipment and collection and production of data for all experiments were primarily the responsibility of the industry researcher; administration and budgetary matters were handled by the university principal.

Coordination

Coordination within and beyond the research team was informal and generally ad hoc in nature. While it is obvious that communication between team members and other firm staff was frequent, it was not always clear who the actors were in particular instances.

Coordination Within the Project. There was a significant amount of communication between team members in open planning discussions, and in discussion of results at the firm site. Both principal investigators' contributions to these discussions were considered equally influential, and each stressed the "peer" relationship. Other communication during the course of the budget was largely by phone, although one doctoral student made several trips to the firm to discuss particular analytical problems. There were no apparent obstructions to communication either within or between the company and the university. The supportive attitude of firm personnel facilitated communication at several levels.

Coordination and Reporting External to the Project. In spite of the fact that the initial industry researcher was removed from the project in the early stages, communication between himself, his replacement and the university researcher remained constant. There was also communication with others in the firm. Other company personnel were present in the early planning meetings, and the firm principal's supervisor maintained a particular interest in the project. No formal reporting was required of either principal.

Benefits and Outcomes

Technical Outcomes. Both principals expected to publish articles in the near future, and both felt that knowledge gained from the research was of considerable importance. For example, the university researcher felt that the level of detail achieved in the project was significant:

> There are other people doing work with slurry reactors who are going to get fairly useless results because they just have not gone deep enough to know what the problems are in experimentation and interpretation of data for this complex reaction.

Knowledge Utilization. While the industry principals were most enthusiastic about the scientific value of the research, and the significant advantage in knowledge gained over the rest of the industry, the university researcher was even more willing to anticipate significant commercial value in their findings. He felt that final project results would provide reasonable guidelines for industry choice of one conversion process over another. The university principal anticipated development of new research projects in the university as a result of this research, and saw this project as extremely important to the enhancement of graduate students' technical training.

While the participants had received a total of only five or six requests thus far for information about the project from within the firm and university, both anticipated a great deal of interest once their results were published.

Personal Outcomes. Both scientists felt that their prestige among colleagues and peers in the larger scientific community would be positively affected by this project.

All principals also identified personnel recruitment benefits for industry. Specifically, the participating firm in this case would be interested in hiring one of the doctoral students, if they were currently hiring.

There was also a great deal of satisfaction drawn from conducting "first-rate" research and from the collaboration itself. There was a great deal of mutual respect among participants and considerable enthusiasm about the results of the research.

Policy Issues

The industry researchers were most concerned about what they perceived as somewhat opposing research interests between university and industry scientists. They and others interviewed in the firm were most articulate about the kinds of research which have value to industry and the relevance of industry/university collaborations.

One company manager felt that while there are questions to be investigated that pertain to industry's needs, industry has not adequately defined those questions for the universities. His concern was that much of the work performed in universities involved highly complex research to explain very simple phenomena exactly. However, answering these simple questions was not inherently interesting to industry, nor was such research applicable to the complex questions that needed to be addressed. In his view, there was a lot of

merit in answering a very important question approximately.

Another manager in the firm elaborated on this point by describing three levels of research: "primary research," which involves answering questions which have a high probability of producing a commercial product or process; "secondary research," in which there is less likelihood of realizing a commercial product; and "tertiary research," involving "interesting questions such as how many dots in a ceiling tile." It was his feeling that, while industry would certainly fund primary research, it would be less likely to fund secondary or tertiary research.

Both managers felt that the IUCR program was important in facilitating communication between industry and university researchers, and in providing funds for research which may be valuable to industry but not necessarily fundable by industry. IUCR funds were perceived as a lever for involving industries and universities in quality research in areas which would not normally be funded through either industry or university channels.

The leveraging influence of IUCR funds on collaborative relationships was an especially salient issue in light of budget cutbacks in both sectors. The university researcher was of the opinion that companies which in the past had been willing to contribute time and money to collaborative undertakings now might be less inclined to do so. In his words:

> Now it is going to be harder . . . it would be harder now, I think, to sell a program to industry in which they were contributing something significant than it would have been two or three years ago.

In the face of these increased difficulties it was his feeling that government can make a difficult task near to impossible through the level of detail and negotiation required during the application review process:

> . . . the government [must] realize . . . that the higher the barriers that the university person has to leap over in order to sell [the project] to the government . . . [and] . . . industry.
>
> . . . the higher the barriers, the more university people are going to say, "There are more productive ways in which I can spend my time instead of that." Increasing justification for everything one proposes to do, increasing the nit-picking on the budget, each one raises the barriers a little bit higher.

All parties felt that the government could reduce the amount of time and effort spent in task justification and budget negotiations by taking into account the nature of research. According to the university professor:

> It is fair that the principal investigator be required to justify the value of what he proposes to do and to outline what he wants to do initially. But he cannot realistically say what he is going to do in detail over the three years, which is what, many times, you are asked to do. . . . If it is . . . honest-to-goodness research, to some extent the results are unpredictable. If it is predictable, there is no point in spending money to do it. So the very fact that it is unpredictable means I can't tell you what I am going to be doing two or three years from now.
>
> . . . sometimes (but fortunately not very often) you get a project manager who thinks more in terms of procurement and wants to buy research like you would buy a cargo plane.

A final issue that emerged in these interviews involved government's active participation in matching industry and university researchers of like interests, the "broker" or "dating-service" concept. These researchers had mixed feelings regarding this activity. While they felt it to be an appropriate role for the government and a good idea as well, they stressed the importance of prior relationships and prior knowledge of one another's work in such collaborations and did not see how a "dating-service" could accommodate these factors. As the university scientist put it:

> . . . in order for a cooperative thing of this sort to work, each party must have a certain amount of respect for the other's capabilities. I could not go in as a complete unknown, cold, to another company and try to work out a collaborative research program. You have to find common grounds, something that is of interest to both parties, that both parties contribute to, and that both parties get something out of. It is not easy to find these situations.